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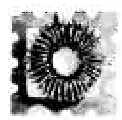
FORMAL ENGINEERING REPORT ON DEVELOPMENT OF

INDUCTOR

MICROELEMENTS



MICRO-MODULE PRODUCTION PROGRAM

SIGNAL CORPS CONTRACT DA-36-039-SC-75968
SIGNAL CORPS SPECIFICATION SCL-6243
MARCH 17, 1958

RADIO CORPORATION OF AMERICA
SURFACE COMMUNICATIONS DIVISION
DEFENSE ELECTRONIC PRODUCTS
CAMDEN 2 NEW JERSEY

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1. ABSTRACT

The abstract presents a synopsis of this report, covering the significant achievements, problems, and highlights of progress on the Inductor Task of the Initial Phase of the Micro-Module Production Program. The microelement inductor work described here comprises Task 3 of the Micro-Module Program.

1.1 PURPOSE OF TASK

The inductor task under the Initial Program had three broad objectives; to demonstrate manufacturing feasibility, to demonstrate microelement-inductor reliability, and to establish sources of supply for cores and inductors. All three of these broad objectives were achieved.

In addition to broad program objectives, specific technical objectives were established for inductors as a component group and for individual types of inductors. Core materials and inductors of various types had to be produced for use in micro-module circuits, and both cores and inductors had to be compatible with over-all micro-module objectives. All three of these basic technical objectives were achieved.

Preliminary-, prototype, and final-grade inductors were to be fabricated and delivered in various quantities. Preliminary units were required to meet room ambient performance objectives only and to demonstrate feasibility. Suitable materials and process requirements were then to be established to meet overall performance requirements. Effort was required on core materials, wire, coatings, mounting and termination, windings, and assembly and treatment. Requirements were to be determined in all of these detailed areas, and optimum materials and processes established for use in prototype and final-grade microelement inductors. The prototype units were to be made to demonstrate performance capability of the selected materials and processes. Nine different types were required in the basic frequency areas of 192 kc, 4.3 mc, and 50 mc. Final-grade inductors were to meet all performance requirements and meet the needs of final-grade micro-modules.

1.2 PROBLEMS AND SOLUTIONS

Technical requirements were especially stringent for microelement inductors because of the form factor and very small sizes required and because of the close tolerances required by circuit parameters. The inductors used in final-grade micro-modules required control of core parameters beyond normal practice.

The temperature coefficient characteristics of the cores presented a primary challenge. Ferrites, produced in the RCA Materials Laboratory at Needham, Massachusetts, provided a material for 1500-μH inductors, but the NPO temperature characteristic necessary for i-f and r-f applications was not completely met. The lowest temperature coefficient that could be reproduced in a low-permeability ferrite was -90 $\pm$70 parts per million per ^{o}C. Extension I of the contract provides powdered-iron cores which approach the NPO temperature coefficient required.

Most ferrites, when operated at the specified low flux level, show an excessive drive sensitivity. This problem has been solved in Program Extension I, by the use of powdered-iron cores. The permeability of powdered-iron cores is also considerably less sensitive to magnetic fields than that of ferrite cores.

During the micro-module assembly process all microelements were coated with silicone elastomer, DC-271, as an impregnant and cement to prevent direct adhesion of the encapsulant to the components to reduce effects of the encapsulant on temperature coefficients. A Teflon coating on the unwound ferrite core further reduced this effect.

Considerable work was devoted to inductor winding methods. Early experiments resulted in insulation damage when the wire was unwound from the winder bobbin and wound onto the core. Damage was minimized by refinements in winding technique and through the use of nylon coated magnet wire.

Special impregnants were needed to permanently locate coil turns without constricting the core or windings.

Coil uniformity was difficult to achieve in early stages because of winding tension control problems. Best results were obtained when maximum winding tension was used and when coils were wound on Pliolite-coated cores.

Early attempts to wind r-f transformers gave unsatisfactory results due to faulty placement of secondary windings. Use of a special core holder in conjunction with a segment winder improved both the uniformity of angle occupied by the primary, and improved the uniformity of locating the secondary start. All types of cores were wound with a total error not exceeding ± degrees.

Testing required special attention to temperature-coefficient, drive sensitivity, and permeability measurements. The specified temperature-coefficient tolerance was beyond the accuracy of conventional equipment, and it was necessary to design special equipment. Temperature coefficients were measured by applying test windings to the cores, and using a dynamic test which provided continuous monitoring of inductance as temperature was varied. A shorted-turn permeameter was used to provide fast measurement of basic core parameters.

1.3 HISTORY

1.3.1 ORDER OF EVENTS

Investigations began with core configurations, and included toroids, pot cores, cup cores, and E-core constructions. A toroidal core was selected because it best met the requirements of self-shielding, low stray field, mechanical stability, and adaptability to production.

No available ferrite had an acceptable temperature coefficient, but it appeared that it could be controlled to tight limits and offer a higher permeability than that available in powdered-iron cores. Core production effort was divided in applications for 100 kc to

1 mc, 1 mc to 10 mc, and 50 mc to 70 mc. Inductance values ranged from 2.4 μH to 1500 μH. A winder for subminiature toroidal coils was adapted to production needs.

Preliminary inductors were wound on available ferrite cores. Prototype modules were made on improved ferrite cores and exhibited stabilities of approximately ±20 kc in 4.3-mc I-F circuits. Tuned-circuit stability of final-grade modules with further improved ferrite cores was ±12 kc. However, powdered-iron cores, developed under Program Extension I and used in most final-grade module i-f applications reduced the variation to ±7.5 kc.

1.4 SPECIAL EQUIPMENT DESIGN

RCA developed a new type of winding shuttle which could be opened to deliver a finished coil without disturbing the remaining load. This machine was used to wind R-F coils on 0.200-inch diameter cores. The machine was later improved by incorporation of a "bird-beak" segment winder, which was a joint effort of RCA and Boesch Manufacturing Company.

Because measurement of temperature-coefficient tolerance was beyond the accuracy of conventional equipment, special equipment was designed for making dynamic tests. Other equipment was also developed for measuring drive sensitivity.

1.5 DESCRIPTION OF TESTS AND PERFORMANCE DATA

Inductor testing was divided as follows: core testing, prototype-inductor evaluation, acceptance testing of final-grade inductors, and final-grade inductor micro-elements both for delivery to the Signal Corps and for use in final-grade micro-modules.

The test program for prototype inductors was conducted to assess the performance of elements using the materials and techniques selected for final-grade designs. All final-grade inductors were tested for all specified parameters and for life and environmental performance in accordance with final-grade inductor specifications.

1.6 PRODUCT COMPARISON

The toroidal design used for microelement inductors can be compared to conventional coils of the pot-core, cup-core, and slug types. Because of close spacing within the module, self-shielding and stray-field effects are important considerations for micro-element inductors. The toroidal construction offers the highest degree of shielding of any configuration. It also makes possible a great range of inductance values because of its excellent permeability characteristics.

The toroidal construction was selected as a compromise in which the advantages of self-shielding, flat structure, mechanical stability, and low distributed capacitance were obtained at the expense of higher cost, less convenient adjustment procedures, and somewhat less flexibility.

The cost of toroidal construction is inherently higher than that of pot-core, cup-core, or slug construction primarily because of winding technique. Toroids must be wound one at a time; conventional coils can be wound in multiple.

1.7 CONCLUSIONS

The three broad objectives of the Inductor Task--viz., to demonstrate manufacturing feasibility, to demonstrate inductor capability, and to establish supply sources--have been achieved.

Feasibility was demonstrated by production of various cores and inductors over the range from 100 kc to 50 mc. Tests proved that their reliability was of a very high order. The RCA Needham Laboratories produced ferrite cores of the required characteristics for preliminary, prototype, and final-grade modules (powdered-iron cores have since been produced under Extension I by Radio Cores, Inc., for use in critical temperature-stability application of final-grade modules).

All of the basic technical objectives for all types of inductors were either achieved, or an ultimate capability was demonstrated. Inductors suitable for all of the specified module applications were produced and successfully demonstrated.

1.8 RECOMMENDATIONS

Effort should be directed toward improved and thinner packages. Designs suitable for adaptation to mechanized module assembly techniques are required. Improvements in winding techniques are needed to reduce cost and to improve reproducibility. Test costs should be reduced through the adaptation of conventional production test techniques. Other devices, such as piezoelectric ceramics and semiconductors having inductor-like functions, should be investigated. Square-loop devices should be investigated and adapted to the micro-module form factor.

The PEM program under Program Extension II to expand the scope of available inductor types and ranges should be continued.

2. TASK OBJECTIVES AND REQUIREMENTS

The inductor task under the Initial Program had three broad objectives:

1. To demonstrate the feasibility of manufacturing various miniaturized fixed inductors in the micro-module form factor.

2. To demonstrate inductor microelement reliability.

3. To establish supply sources for both cores and inductors, and to make these elements available for use in the Micro-Module Program.

All three of these broad objectives were essential to the achievement of over-all micro-module Program goals, and all three were realized.

These Program objectives could be achieved only through the satisfactory attainment of specific technical objectives. At the beginning of the program, general technical objectives were established for inductors as a group of components. In addition, each type of inductor had to satisfy detailed electrical, mechanical, and environmental requirements to permit its use in specific applications.

General technical objectives required that suitable core materials and inductors of various types be produced for use in micro-modules. The core materials were to meet all the requirements for use in lumped-constant tuned circuits in micro-module form. The cores and inductors had to be compatible with over-all micro-module objectives in terms of reliability, miniaturization, form factor, and suitability for mechanized processing. All of these basic technical objectives were achieved. It was agreed that toroidal coils wound on ferro-magnetic cores were the most logical approach, and these were to be considered as the first choice in design. But, other form factors were to be considered if subsequent investigation indicated that they had additional advantages.

Particular emphasis was to be placed on core materials. Various materials and processes were to be investigated, and cores were to be evaluated in terms of permeability, losses, and the effects of operation at temperature extremes of -55°C and +85°C. Improvements were to be directed toward controlled reproducibility, which was to be demonstrated in final-grade sample inductors.

The requirements for 10 types of microelement inductors needed under the Initial Program are described in the following sections.

2.1 GENERAL TASK REQUIREMENTS

2.1.1 PRELIMINARY-GRADE INDUCTORS

Preliminary-grade inductors for the three basic frequencies of 192kc, 4.3 mc, and 50 mc were required to demonstrate basic feasibility of the concept only, and

performance objectives were correspondingly limited. Consequently, preliminary-grade inductors were required to meet initial performance objectives only, and were not subjected to life tests or environmental tests.

During this phase, such practical factors as wire size, insulation, impregnation, and encapsulation were to be evaluated. In addition, the effects of incorporation of micro-element inductors into micro-modules were to be investigated. The preliminary-grade inductors were to be tested to determine their compliance with specifications, and the test data were to be delivered to the Signal Corps.

2.1.2 PROTOTYPE-GRADE INDUCTORS

In the prototype phase, particular attention was to be given to inductor temperature coefficients, and effort was to be made to attain control and reproducibility. Inductor designs were to be refined, and environmental behavior was to be evaluated. Characteristics of encapsulated inductors were to be investigated further, and particular attention was to be given to the effects of the encapsulant and the encapsulating process upon temperature coefficients.

Prototype-grade inductors were to be fabricated for each of the contract module applications. Included were the following inductor types:

a. 50-mc input and mixer transformers

b. 45.1-mc crystal oscillator output transformer

c. 4.3-mc interstage i-f transformer

d. 4.3-mc limiter and discriminator transformers

e. 192-kc oscillator inductor

f. 50-mc M-derived L-C decoupling inductor

g. 4.3-mc M-derived L-C decoupling inductor

h. 1.5-μsec 750-pps blocking-oscillator transformer

i. 192-kc pulse-shaper inductor

j. 96-kc gate inductor

Experimental winding equipment was to be developed, and the effects of machine winding on inductor parameters were to be evaluated. Tentative selections of adhesives, impregnants, and wire insulation were to be made in the prototype phase.

Tests were also to be made to determine the extent of compliance with RCA specifications. The test data were to be delivered to the Signal Corps.

2.1.3 FINAL GRADE INDUCTORS

Final-grade inductors were to incorporate changes and refinements necessary to qualify them for use in final-grade micro-modules. Refinements were to be made, where necessary, in cores and inductors of each type. Final design parameters and electrical values were to be established for microelement inductors in basic application. Inductor samples were to be constructed and tested in micro-modules. The final-grade inductors were to be tested for compliance with the applicable RCA specifications and applicable requirements of other specifications. Complete test data on these inductors were to be delivered to the Signal Corps.

2.2 MATERIALS AND PROCESS REQUIREMENTS

Successful design of miniaturized microelement inductors required that extensive investigation be conducted into materials and processes. These factors were considered essential to the satisfaction of Initial Program inductor requirements.

Core Materials -- Core materials suitable for the required range of inductance values had to be selected or modified. The materials had to be adaptable to the micro-module form factor, and had to meet the performance and stability requirements for micro-module inductors.

Wire -- Wire of suitable sizes and insulating materials had to be selected.

Coatings -- Suitable coil-treatment methods and impregnants had to be evaluated and selected so that reliable inductor performance would continue after the encapsulation in the module.

Mounting and Termination -- Substrates on which inductors could be mounted and terminated had to be selected.

Windings -- Winding techniques were to be selected or designed for the ultimate core geometry to provide for volume production, high uniformity, high reliability, and reasonable production costs. Methods for the precise placements of turns on the cores had to be determined to insure predictable performance.

Testing -- Testing of core materials for magnetic properties and loss characteristics prior to winding was a task requirement. Testing of wound inductors for performance characteristics and uniformity of specified inductor parameters, both electrical and mechanical, was also necessary.

Assembly and Treatment -- Production assembly and treatment techniques were to be established.

2.3 PERFORMANCE REQUIREMENTS

Both general-purpose and precision inductors were to be made under the Initial Program. The precision types had relatively critical stability requirements; the general-purpose types did not. Performance specifications for inductors in general were as follows:

Parameter	Precision Type	General-Purpose Type
Inductance Range (μh)	0.3 to 50	2.4 to 1500
Frequency (mc)	4 to 50	0.1 to 50
Quality Factor (Q)	up to 100	up to 75
Operating Temperature (^{o}C)	-55 to +85	-55 to +85
Max. Operating Voltage (dc volts)	100	100
Max. Operating Current (dc ma)	100	100
Temperature Stability of Inductance	$\pm$0.5%*	$\pm$5%
Temperature Stability of Q	$\pm$15%	$\pm$50%
Drive Sensitivity	$\pm$0.05%	$\pm$20%

*compensated

Environmental-Test Requirements:

Shock and vibration	
Moisture resistance	
Immersion	No mechanical or electrical degradation in excess of above limiting values for related parameters; 15,000 hours mean time to failure.
Overload	
High-temperature storage	
Load life	
Insulation resistance and dielectric strength	1000 megohms min., 100 dc volts max.

2.4 SCHEDULE FOR DELIVERY

The general plan for delivery of microelement inductors was established as follows:

Item	Description	Quantity	Delivery Date
1	Preliminary microelements for use in preliminary modules and for evaluation	72	Aug. 1, 1958
2	Prototype microelements for use in prototype modules and for evaluation	69	Feb. 1, 1959
3	Final-grade microelements for final-grade modules for sub-assemblies	359	Sept. 1, 1959
4	Final-grade microelements for acceptance testing	200	Jan. 1, 1960
5	Final-grade microelements for final-grade modules for acceptance testing	575	Jan. 1, 1960
6	Final-grade microelements for delivery to the Signal Corps; A-test data required	200	March 15, 1960

The following final-grade microelement inductors were required under Item 6, above:

a. 30 1500-μH chokes

b. 15 4.3-mc i-f transformers

c. 20 38-μH r-f chokes

d. 15 limiter transformers

e. 15 4.3-mc discriminator transformers

f. 15 50-mc r-f transformers

g. 15 50-mc oscillator transformers

h. 15 2.4-μh r-f chokcs

i. 15 600-μh chokes

j. 15 350-μh chokes

k. 15 mixer transformers

l. 15 pulse transformers

Because of subsequent revisions in subassembly requirements and changes in the Design Plan, quantities were modified as follows:

Item	Quantity
1	72
2	69
3	293
4	158
5	484
6	200

3. NARRATIVE AND DATA

The Micro-module Program was undertaken as an Industry Preparedness measure. Consequently, a prime objective was to establish a micro-module capability in the shortest possible time. The time factor dictated that state-of-the-art devices, materials, and processes be used in all Program phases.

Technical requirements for individual microelement inductors were stringent, however, and no electrically equivalent inductors of conventional design were available in sizes small enough for incorporation into micro-modules. Program inductor requirements presented challenging engineering problems, especially in the area of core materials.

Conventional ferrite and powdered-iron cores had been made in substantial quantities by various manufacturers, and their manufacturing techniques and characteristics were well established. The precision requirements for microelement inductors, coupled with their small form factor, however, presented new problems in core-material formulations, processing, testing, and repeatability of manufacture.

At the start of the Program, no company had this complete technology, and no related programs could be drawn upon as sources of information. RCA had extensive experience, however, in the production of small cores for computer and communication applications. The cores needed for microelement inductors were produced by the Radio Cores Co. and the RCA Needham, Mass., Laboratory, which is a part of the RCA Semiconductor and Materials Division. The inductors were produced by RCA, Somerville, N.J. The resulting cores and inductors used in final-grade micro-modules were an advance in the state of the inductor art, and met the basic requirements for Initial Program modules.

3.1 PROBLEMS AND SOLUTIONS

3.1.1 CORE MATERIAL PROBLEMS

The performance requirements described in Section 2.3 of this report imposed close tolerances upon the magnetic core materials, and the selection of these materials became a major part of the inductor task. The principal characteristics which required extended engineering effort are described in the following sections.

3.1.1.1 TEMPERATURE COEFFICIENT

The specifications for the 4.3-mc sections of the AN/PRC-34 Radio Set required that tuned circuits have a temperature stability of ±10 parts per million per ^{o}C. Temperature-compensating capacitors having NPO characteristics were chosen for use in these circuits to reduce over-all temperature-coefficient problems. The magnetic cores were also required to have NPO characteristics.

Other applications required inductance values up to 1500 μH with temperature stabilities of ±3.6 per cent over the temperature range from -55°C to +85°C. A ferrite material, XF-3988, was produced by the RCA Materials Laboratory at Needham, Mass., for the 1500-μH application. The NPO characteristics, which were especially demanding, were closely approached in ferrite. Batches of cores having temperature coefficients of ±50 parts per million per °C were made. Although this characteristic was a marked advance in capability for ferrite units, the uniformity of temperature coefficient was not sufficient, and reproducibility was poor. The lowest temperature coefficient that could be consistently reproduced in a low-permeability ferrite core was -90 ±70 parts per million per °C. Note: Extension I of the Micro-module Program provided for powdered-iron cores having temperature coefficients of 25 ±10 ppm/°C, a characteristic which approached the required temperature stability.

3.1.1.2 DRIVE SENSITIVITY

The discriminator circuit of the AN/PRC-34 was required to operate beyond the voltage-level range over which the limiter stage could supply constant input voltage. Consequently, the magnetic material used in the discriminator circuit had to have a constant permeability over a 1-to-5 voltage range. When operated at low flux levels, most ferrites have excessive drive sensitivity. In this application, cores from individual firing batches had uniform drive sensitivity, but the sensitivity varied between batches. The scheduled effort under the Initial Program did not allow further investigation into the firing process to determine the causes of variations. Note: Under Program Extension I, the permeabilities of powdered-iron cores varied less than 0.1 per cent over an excitation range of 1 to 30 oersteds. These latter cores satisfied discriminator-circuit requirements.

3.1.1.3 MAGNETIC STABILITY

Because of their domain structure, most ferrites have poor magnetic stability, and strong magnetic fields will change their effective permeability. Both positive and negative changes in permeability can be effected by spurious fields; the nature of the change depends upon the orientation of the core in respect to the spurious field, and upon the core's magnetic history. For example, type XF-4226 cores underwent ±8 per cent changes in permeability after being subjected to magnetic fields of different orientations.

Powdered-iron cores are considerably less sensitive to the effects produced by such spurious fields. Cores of SF carbonyl iron powder have magnetic stabilities which exceed 0.2 per cent in the presense of magnetic fields of 100 oersteds.

Ferrite cores which are required to maintain specified magnetic characteristics must be isolated from external magnetic fields, such as those produced by soldering devices and power transformers.

Optimum processing conditions and design factors were evolved to stabilize the permeability of the microelement inductors produced under the Initial Program. Because over-all inductor performance must often involve compromises in permeability,

quality factor, and inductance value, however, the resultant magnetic-stability characteristics of the ferrite cores were not as good as desired. Note: The powdered-iron cores produced under Extension I displayed much better stability performance in the presence of spurious magnetic fields.

3.1.1.4 COATING

During the micro-module assembly process, all microelements are coated with DC-271, a silicon elastimer, to prevent direct adhesion of the encapsulant to the components. Early experiments showed that the encapsulant had an adverse effect upon inductor temperature coefficient -- despite the use of DC-271. A number of remedies were tried, including heavier coatings of DC-271 and coatings of DC-271 having increased solid content, silicon resin, rubber, and flexible polyurethane. Although some of these coatings had desirable properties, none proved to be a universal remedy. The coatings which had the best characteristics were DC-271-M1 and -M-9, a Dow Corning commercial preparation modified for micro-module needs, and RTV-20 and RTV-60, which are room-temperature vulcanizing silastics made by the General Electric Company. Experiments showed, however, that Teflon, manufactured by the DuPont Company, solved the problem when the Teflon was applied as a coating to the unwound ferrite cores. The Teflon coating also improved the winding condition, and prevents cutting of the wire insulation by core edges during winding.

3.1.2 PROBLEMS WITH WIRE

3.1.2.1 INSULATION DAMAGE

The preloaded-shuttle method for winding toroids was used for all microelement inductors, although this method damaged the magnet wire. Prior to being loaded into the shuttle, the wire is spiraled on a 0.01- to 0.20-inch diameter mandrel. The insulation can be damaged when the spiraled wire is forced into the hollow ring shuttle. During coil winding when the wire is unspiraled and makes a right-angle turn against the relatively rough inner surfaces of the stainless-steel nozzle. The wire may also be scuffed against the hard, rough surface of the ferrite core.

Throughout the coil-production operation, it was necessary to monitor the winding process to detect exposed copper on the wire. When wire having a heavy coating of Formvar was used, most damage resulted during the unspiraling operation, when copper was exposed during the axial pull of the unspiraling wire against the shuttle edge. This damage produced shorted coils in the early stages of the Program, but the damaged was minimized when wire tension was relaxed. Improvements in the spiraling mandrel and reduction in tension essentially eliminated shorted turns on later coils.

An insulation resistance of 1000 megohms was required between windings, and efforts were made to meet this requirement through further process improvements. The nozzle material was changed to nylon, which did not damage the wire. Nylon, however, had a low friction coefficient, resulting in insufficient tension on the wire. With the introduction of the nozzle-attached shuttle, stainless steel was again tried. This

arrangement permanently positioned the nozzle. With proper stoning of the nozzle, well-wound coils could be produced. Usage further improved the inside surface of the nozzle. When this system was used to wind coated, ferrite cores, the 1000-megohm specification was met after the coils had been treated. Eventually, nylon-coated poly urethene-insulated wires were introduced, reducing the exposed copper before treatment.

3.1.2.2 STRIPPING

Termination of a 6-lead 0.200-inch-diameter transformer on a microelement wafer requires that all six leads be connected to their correct notches without introducing shorts between any of the wires or notches. When Formvar-insulated magnet wire was used, accurate stripping was accomplished by the tedious process of dressing leads on a dummy element under a 10-power microscope. The precise points for stripping were marked on the leads. The coil was then removed, the leads were straightened, and stripper was applied with a brush or toothpick to the marked portion of the lead. This latter step was performed under a microscope. The stripper and Formvar insulation were then removed by rubbing the wire with an absorbent paper. The lead was then tinned and dipped into the stripper solvent. Finally, the coil was mounted on its wafer, the leads were dressed, and the ends were soldered.

In addition to being tedious, this method of stripping did not produce a clean break between the insulation and the tinning. When the use of nylon-coated poly urethane-insulated wire was introduced, dip tinning was successfully adopted. In small quantities, coil leads are individually marked and dipped. In large quantities, a splatter shield is used over the soldering pot. This shield includes measuring means which keep the proper lengths of insulated wire above the solder; all leads are tinned simultaneously.

3.1.2.3 MOUNTING AND CEMENTING

Because final-grade ferrite cores were pressure sensitive, special impregnants were needed to permanently locate the turns without constricting the core or windings, even under extremes of temperature, shock, or vibration.

Dow Corning DC-271, an elastomeric, pressure-sensitive adhesive, was selected. This material served as both an impregnant and a cement. Because DC-271 never hardens, it allows the inductor assembly to equalize stresses or strain imparted from the environment. The material is compatible with other module materials, and provides superior moisture protection.

DC-271 is tacky, however, and special Teflon holding fixtures were developed to permit the treated inductors to be handled.

3.1.2.4 LEAD DRESS

The small diameters of microelement inductor leads (0.002 to 0.008 inch) presented handling and processing problems. On inductors having only a few turns, the lead

dress was critical because nonuniform lead dress can cause variations in coupling and leakage inductance.

To insure uniform lead dress, assembly drawings detailed the lead paths, and allowance was made for movement of coil windings during enca sulation and environmental testing.

3.1.3 WINDING PROBLEMS

3.1.3.1 TENSION CONTROL AND WIRE-SIZE LIMITATIONS

The problem of wire-insulation damage during winding was described under Section 3.1.2.1 above. Early attempts to wind AWG 44 wire spiraled from a 0.010-inch-diameter mandrel and wound through an 0.013-inch-diameter nozzle hole resulted in very loose turns that moved about on the core.

Use of a 0.015-inch diameter spiraling mandrel and a 0.006-inch nozzle-hole diameter increased the winding tension into the usable range. The 0.015-inch mandrel and a 0.008-inch-diameter hole brought AWG 38 wire tension to a desirable value. All of the machine-wound inductors in the Program are within the AWG 44 to AWG 38 wire-size range. <u>Note</u>: Boesch Manufacturing Company, the manufacturer of toroidal-coil winding machines, has more recently extended the range from AWG 46 to 36, and can supply coded combinations of mandrels and shuttles (nozzles) that produce usable tensions.

3.1.3.2 COIL UNIFORMITY

The problems of producing a uniform bank-wound toroid multiply as the wire diameter is increased. With the inherent intermittent tension, the wire cannot be looped into specific between-turn slots, and a more or less random build-up results. This randomness increases with lack of tension and with any changes in the core-speed-to-winding-speed ratio.

Friction core drives are undesirable for coils more than one wire diameter deep because, as the coil enters under the drive pulley, the core speed decreases, changing the winding pitch and bulging the winding.

Uniformity problems caused by intermittent tension were minimized by holding the winding loop in the shuttle plane as long as possible and releasing the loop just as it pulled tight on the core. This procedure prevents the turn from being badly displaced by the camber remaining in the wire after spiralling.

In the case of powdered-iron cores and other cores not teflon coated, best results were obtained when maximum winding tension was used and when coils were wound on Pliolite-coated cores. As the turns were pulled tight, indentations were made in the Pliolite. On the next turn, the wire re-enters this indentation rather than falling into a random location.

3.1.3.3 SECONDARY WINDING PLACEMENT

Early efforts to wind R-F transformers utilized friction core drive of the modified Boesch Model SM toroid winder. The technique was to spread a primary winding over the entire core, reverse the core rotation at the finish, and then to wind the secondary. Transformers produced by this method showed poor coupling and poor unit-to-unit coupling uniformity.

Moving the secondary winding into the middle of the primary produced tighter coupling, but repeatability remained poor. Attempts were then made to accurately fix the location of the secondary with respect to the primary finish by counting the turns of the shuttle as the core was idled into the secondary start position. This method was unsuccessful because of variations in the drive friction with coil build-up.

Use of a core holder (segment winder) improved both the uniformity of angle occupied by the primary and improved the uniformity of locating the secondary start. Although winders have two friction drives for relating core rotation and shuttle rotation, the total error introduced is less than ± 5 degrees, and all types of coils can be wound satisfactorily with this error.

3.1.3.4 LEAD IDENTIFICATION

Lead identification even on prototype quantities of five- or six-lead R-F transformers posed problems from the start. When the coil was affixed to the microelement substrate, the length of magnet wire between the coil and the terminal notch could be as little as 1/16 inch. In a well-designed high-frequency element, all leads are as short as possible. Coding should logically be done while winding, but a permanent color code between coil and terminal is not practical since it is not practical to locate the colors with precision while the coil is on the machine. Coding is therefore accomplished on a portion of the lead which is later removed. If stripping or tinning is done by dip methods (Formvar in Super-X or Nyleze in hot solder) it often becomes necessary to reapply the coding after the dip. Recent work indicates that colors can be found that will withstand the hot solder and can be used on Nyleze insulated wire. In any case, the removal of the code with the excess wire at assembly prevents inspection of assembly wiring from being a relatively simple operation, as it is in larger assemblies.

An alternate system of coding involves identifying leads by their lengths. Start leads and even numbered taps were made approximately two inches long and finish leads and odd numbered taps, approximately one inch long. This system preserves the lead identification up to the assembly point. After assembly suitable tests may be performed to determine proper hookup as well as phasing of secondary windings.

3.1.3.5 LOOSE TURNS

Loose turns may somtcimes be caused by an improper winding. The following are the causes of loose turns:

a. When fine wire (AWG 44) was wound, the turn-counter and guide-brush friction became appreciable with respect to the shuttle (winding) tension and sometimes a turn hung up temporarily on the brush was not pulled tight by turns that followed. This was caused by faulty setup and, once noticed, could be corrected.

b. Because of the random nature of toroidal bank winding, deep coils have a few loose turns. This undesirable feature was aggravated in core vise winding when the center of rotation of the core moved outside the shuttle plane and turns were applied in other than a radial manner. Thus applied, a turn is larger than it should be and, frequently, when the coil was handled the turn fell into a radial position and became loose. This effect will be reduced by planned future refinements of the core vise turret by Boesch Manufacturing Company.

c. Transformers designed with a tap in the first winding are a potential source of loose turns in the second winding, near the tap. To avoid this effect, the machine was stopped with the tap precisely in the shuttle plane and the tap lead was moved across the plane. A few turns were wound over the tap lead and when the lead was again dressed radially, these turns appeared loose. However, these turns did not readily move about and caused no difficulty.

d. During the early part of the program, loosely wound turns were quite prevalent, especially when winding with insufficient tension on sharp-cornered ferrite cores. Tumbling the cores to round off the corners and reducing the friction by coating the cores with Teflon did much to improve the anchoring of the winding. Further improvement has been achieved by coating the core with Pliolite S-7 and later dipping it in toluene. The solvent fillets the Pliolite around each turn that is near the core, binding it securely.

3.1.4 PROBLEMS IN TESTING

Inductor test methods had to be worked out to make the measurement accuracy compatible with module circuit requirements. Problems arose in measuring temperature coefficient, drive sensitivity and permeability.

3.1.4.1 TEMPERATURE-COEFFICIENT MEASUREMENT

The specified temperature-coefficient tolerance was beyond the accuracy of conventional equipment, such as Q meters or inductance bridges. Special temperature-coefficient equipment, described in Paragraph 3.1.2.3, was designed. The temperature coefficients of the magnetic cores were measured by applying test windings of approximately 10 μH to the cores. Point-by-point measurement techniques did not provide satisfactory information about the influence on all parameters concerned. Most ferrites have very nonlinear temperature coefficients and the influence of restrictive coatings led to erratic readings. A dynamic temperature-coefficient test provided the most informative results. The equipment recorded a graph showing inductance as a function of temperature. Corrections were made for variations of the quality factor during the temperature cycling.

3.1.4.2 DRIVE SENSITIVITY MEASUREMENT

A drive-sensitivity-test method was designed to accommodate the measurement of drive stability to an accuracy of ±0.1 per cent over a 1-to-5 drive change. The required accuracy eliminated regular Q-meter measurement and the required change in drive made a normal inductance-bridge measurement difficult. Two methods seemed best suited, an impedance comparator and a phase-indicator method. A phase indicator was chosen since it was usable over a wide range of operating frequencies. The test setup is shown in block-diagram form in Figure 3.1.4-1. Calibration curves were prepared to determine the influence of other parts of the associated circuitry on the indicated phase shift.

A direct phase measurement on the Q meter simplificd the test operation (Figure 3.1.4-2) and gavc accurate results. An oscilloscope was incorporated as a resonance indicator. The frequency was controlled by a frequency meter, and the incremental-capacitor dial of the Q meter had sufficient resolution to achieve an accuracy of ±0.1 per cent.

3.1.4.3 MAGNETIC PROPERTIES OF CORES

Testing of the magnetic properties of miniature toroidal cores is usually accomplished by applying suitable standard windings and making electrical measurements of characteristics of the windings on the cores.

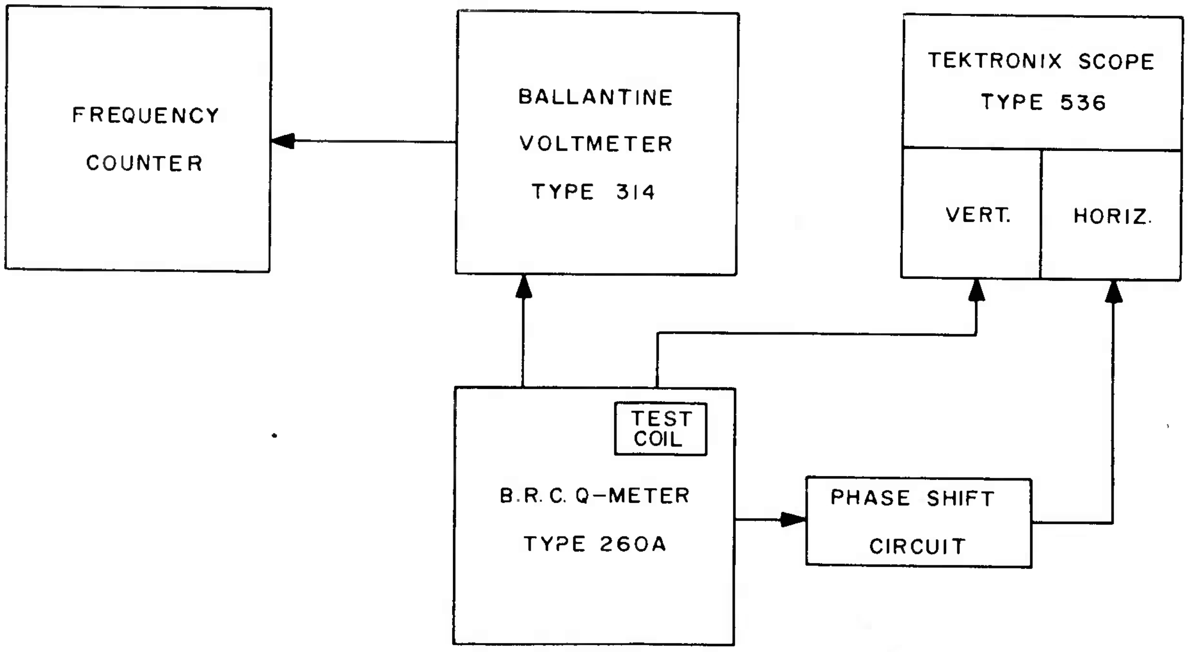

FIGURE 3.1.4-1. Test Setup for Measuring Drive Sensitivity.

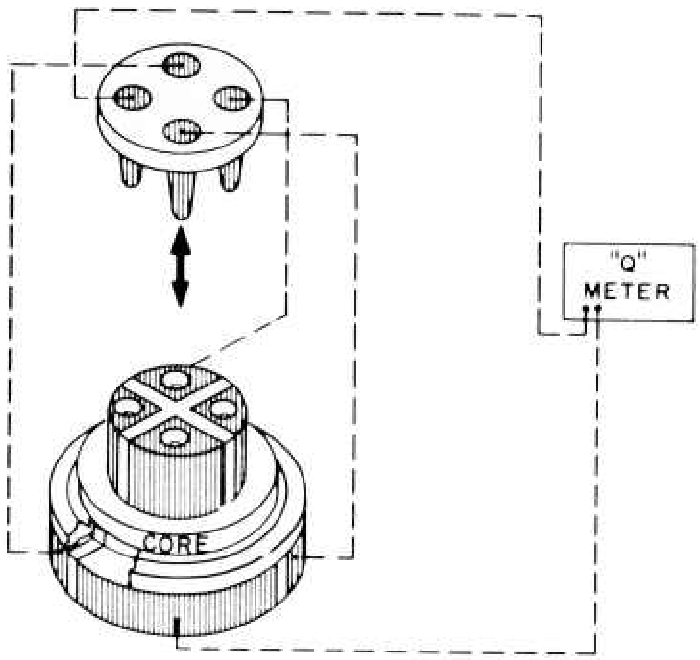

FIGURE 3.1.4-2 Original Split-Pin Permeability-Test Fixture

When a considerable number of cores are involved, and accurate measurements are required, this method becomes cumbersome. An alternate system involves the use of a text fixture which is essentially a quick acting multiturn winding which links the core.

The first approach to this testing problem was to design a split-pin type of test fixture that would effectively link the toroidal core with several turns. These turns would then be connected to a suitable test instrument. Some mechanical limitations of such a device are: poor contact resistance, high leakage inductance and inaccuracy of reset.

Such a device was constructed, however, and some success was achieved. Limitation of the range of core permeabilities, test frequencies, and reset accuracy were very apparent. A sketch of the working parts is shown in Figure 3.1.4-2. With the diversification of core types and test frequencies and the need to grade cores for losses as well as effective permeability, the need for a more flexible and reliable type of test jig was apparent.

Based on principles described in National Bureau of Standards publications, a shorted-turn permeameter was designed for use on Micro-Module miniature toroidal cores. This device consists essentially of a transformer with a quick-acting shorted-turn secondary. The shorted turn links a primary winding wound on a suitable toroidal core which is built into the fixture. A coaxial center pin links this primary coil with

a cover that may be conveniently opened for the insertion of a test core.

This type of fixture has considerable flexibility in that suitable primary windings may be prepared for any range of test frequencies and any range of core permeabilities. Further, the mechanical features of a single-turn secondary permit a workable jig to be fabricated with reasonable dimensions considering the microelement core size.

The accuracy of this device permits permeability to be compared to that of a standard reference core within approximately ± 0.1 per cent and losses to be compound within approximately ± 1 per cent when the jig is used in conjunction with a standard laboratory-type Q meter. Figure 3.1.4-3. Greater accuracy for permeability measurements may be obtained by using this permeameter in a variable-frequency oscillator in conjunction with a frequency counter. Manual testing rates for permeability and Q of 100 cores per hour have been attained.

A close-up of the open permeameter with core in position on permeameter pin is shown in Figure 3.1.4-4. Figure 3.1.4-5 is an assembly drawing of this permeameter.

3.1.4.4 WINDING TESTS

Testing of toroidal windings before mounting on suitable substrates presented problems dealing with reproducibility of results and adaptability to available test instruments.

Fine-wire leads presented unpredictable leakage inductance particularly in high-frequency low-inductance windings. Handling of these small elements also introduced variations in their inductive and coupling values. It was necessary to develop suitable standard test fixtures and test techniques in order to properly control the electrical values through winding, testing, assembly into microelements and, finally, assembly into Micro-Modules.

Initially the windings were quite loose on their codes and any handling introduced considerable change in their predicted electrical values. As winding techniques improved, more accurate testing techniques were required.

Special jigs were designed to provide uniform placement of unmounted inductors on the various test instruments. These jigs further standardized the external lead lengths and placement during test. They were prepared in such a way that stray capacitance and inductance of the test jigs were minimized and stabilized. Windings requiring successive connections for the various tests were first mounted on test boards provided with banana plugs so that the coil leads and windings were handled only twice, regardless of the number of connections required between instruments. Test procedures and calibration techniques are described in following sections of this report.

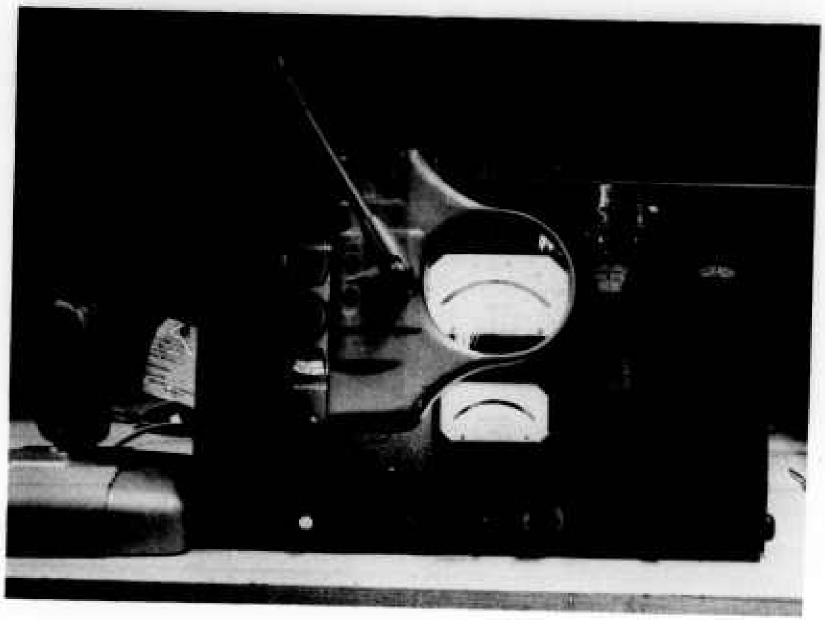

FIGURE 3.1.4-3 Permeameter Core-Test Equipment

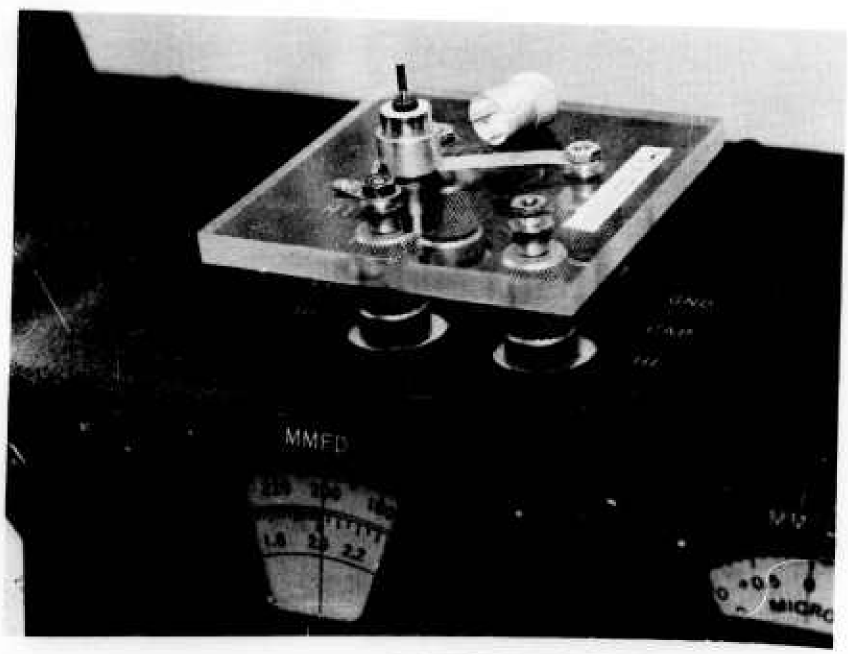

FIGURE 3.1.4-4 Close-up of Open Permeameter with Core in Position on Permeameter Pin

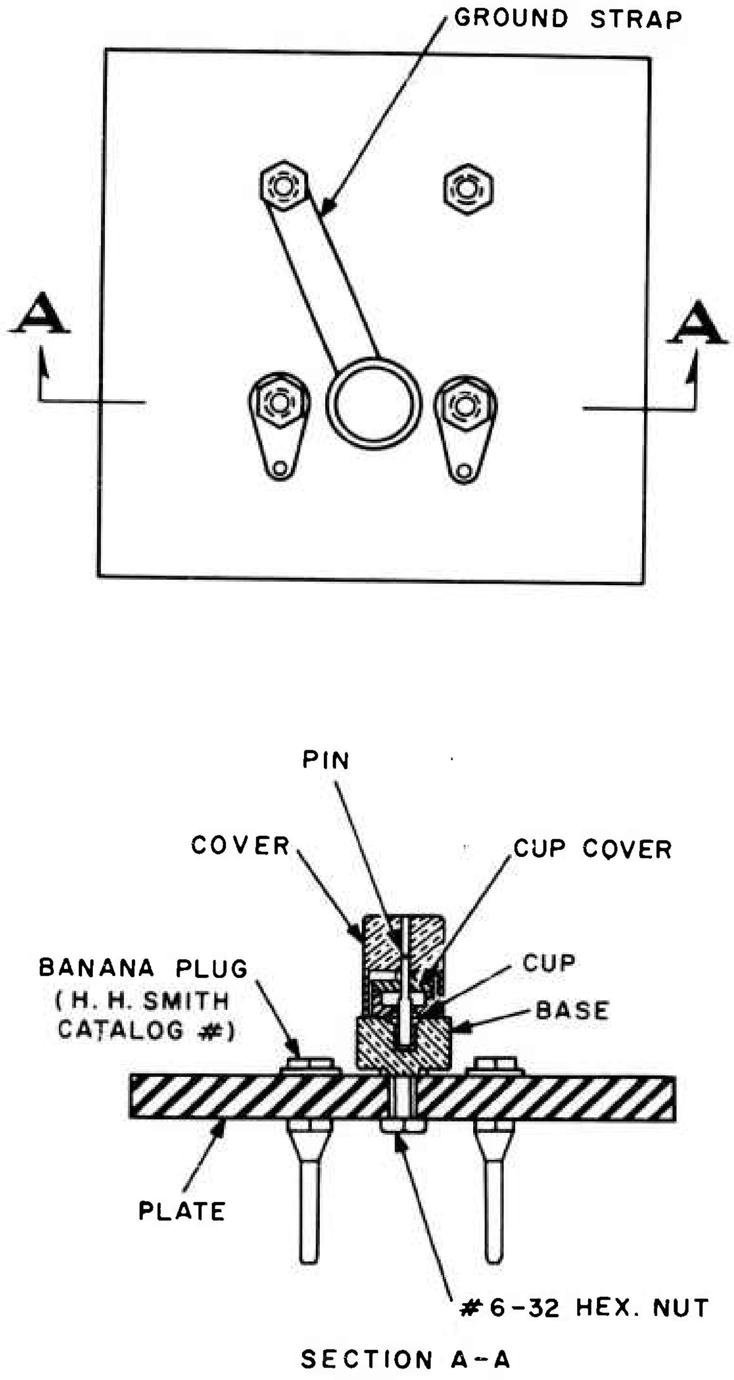

Figure 3.1.4-5 Permeameter Fixture, Assembly Drawing

3.2 HISTORY

3.2.1 ESTABLISHMENT OF SPECIFICATIONS

3.2.1.1 GENERAL INDUCTOR SPECIFICATION

The general specification (RCA A-8972089) covered the design and construction of microelement magnetic cores and inductors, grade 3, class 0 of Specification MIL-C-15305A and was governed by the over-all requirements of the Micro-Module program.

3.2.1.2 REQUIREMENTS FOR MAGNETIC CORES

This specification (RCA A-8948851) covered the detail requirements for magnetic cores to be used for inductor microelements having the following mechanical and electrical characteristics.

Dimensions: Outside diameter: 0.200 $^{+0.010}_{-0}$ inch

Inside diameter: 0.100 $^{+0.005}_{-0}$ inch

Height: 0.050 $\pm$0.002 inch, edges to be rounded

Permeability tolerance: $\pm$8 per cent of nominal

Q tolerance: $\pm$20 per cent of nominal

Temperature-coefficient tolerance: $\pm$10 ppm/$^{\circ}$C

Retentivity: Permeability shall not change more than 0.2 per cent after exposure to a 100 Oersted magnetic field

Drive Sensitivity: Permeability shall not change more than 0.1 per cent when core is excited over a range from 0 to 30 Oersteds.

The following tests were specified:

Group "A" Tests

- Visual and mechanical characteristics
- Permeability
- Quality factor
- Temperature coefficient
- Retentivity
- Drive sensitivity

Group "B" Tests

Vibration, shock
Immersion
Moisture resistance

Group "C" Test

Load Life

3.2.1.3 REQUIREMENTS FOR R-F AND I-F INDUCTORS

Specification RCA A- 8972090 covered the detailed requirements for microelement R-F and I-F inductors of the following electrical ratings:

Inductance	0.1 to 1500
Operating frequency	0.455, 4.3, 11.0 and 60 mc
Max. rated d-c current	100 ma

The following tests were specified:

Group "A" Tests

Visual and mechanical inspection
D-C resistance
Inductance
Quality factor
Self-resonant frequency
Drive sensitivity
Temperature coefficient
Dielectric strength
Insulation resistance
Overload
High-temperature exposure

Group "B" Tests

Vibration, shock
Immersion
Moisture resistance

Group "C" Test

Load life

3.2.1.4 REQUIREMENTS FOR PULSE TRANSFORMERS

RCA specification A-8972067 covered the detailed requirements for microelements pulse transformers having the following static and dynamic electrical ratings:

Performance at 25°C

The following performance was required at 25°C both prior to 85°C operation and subsequent to -55°C operation. Applicable test circuit and operating potentials are described in Figure 3.2.1-1 and the output waveform is shown in Figure 3.2.1-2.

Amplitude (no load) 8.5 $\pm$0.5V

Amplitude (loaded) should not differ from no-load valve by more than 0.5V.

A duration $\geq$1.5 μsec

B duration $\geq$ 0.5 μsec

$t_r \leq$ 0.3 sec

C $\leq$ 1.0 V

Trigger level $\leq$ 4.5 V peak to peak

Amplitude 8.5 V $\pm$0.5 V

Amplitude at full load shall not differ by more than 0.5 V from no-load value

A duration $\geq$ 1.0 μsec

B duration 0.5 sec

$t_r \leq$ 0.3 μsec

C $\leq$ 1.0 V

There shall bc no module output pulsc when the input pulse amplitude is reduced to 4.5 V.

3.2.1.5 WAIVERS

Waivers in the following areas of the inductor specifications were approved by the Signal Corps:

a. The I-F ccnter frequency stability requirement was revised from $\pm$4 kc to $\pm$20 kc for all prototype and final-grade Micro-Modules in which ferrite cores were used in the transformers. (This was not applicable to powdered iron cores.)

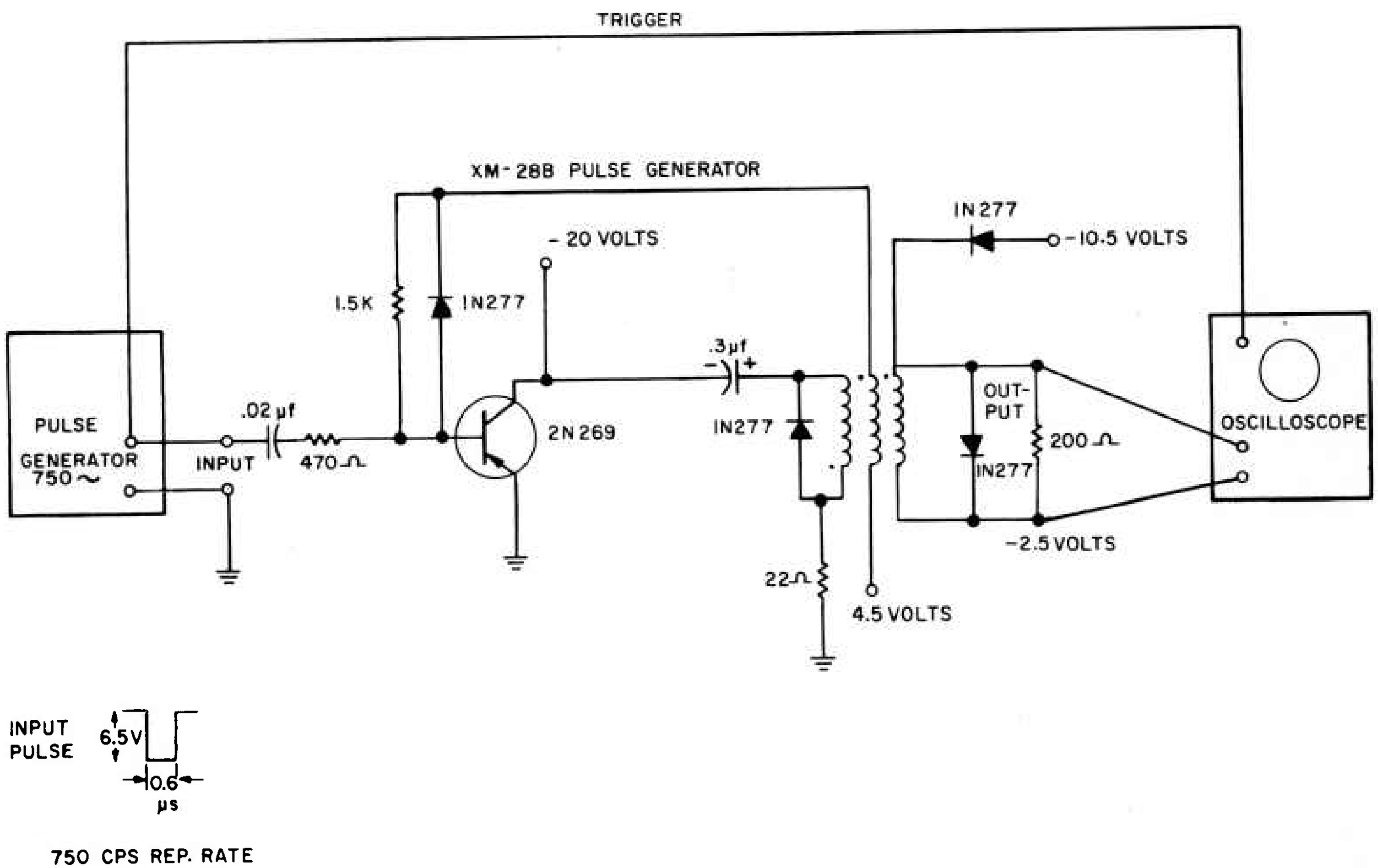

FIGURE 3.2.1-1 Test Circuit for Pulse Transformers

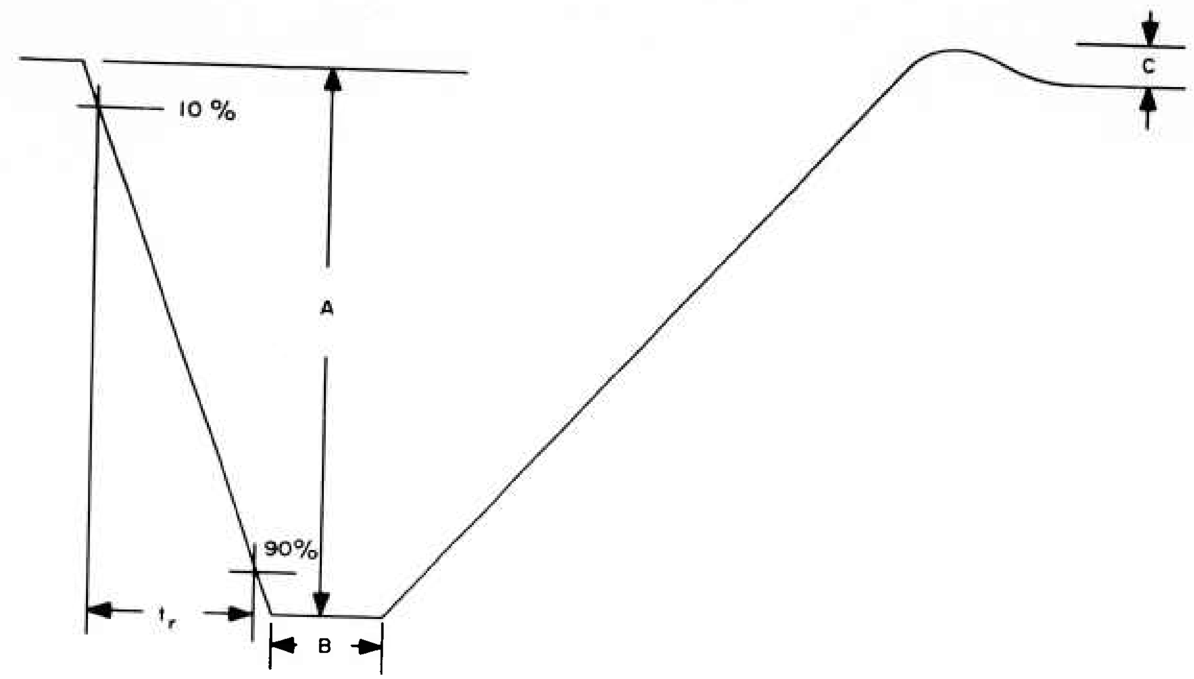

FIGURE 3.2.1-2 Output Waveform of Pulse Transformer

b. The pulse-transformer overshoot requirement, discussed above, was changed to less than or equal to 1.3 volts at the temperature extremes, 1.4 volts or less after "B" testing, and 1.5 volts or less after "C" testing.

c. The requirement for drive sensitivity measurements was eliminated for final-grade transformers for delivery to the Signal Corps.

3.2.1.6 COMPARISON OF INDUCTOR AND MICRO-MODULE SPECIFICATIONS

Table 3.2.1-1 compares the specifications of various inductor elements to the specifications of the modules in which they are used.

Inductor Type	Core Type		Temperature Coefficient of Inductance (%)	Temperature Coefficient of Band Width or Q (%)	After "B" Test: Change in Inductance (%)	After "B" Test: Change in Band Width or Q (%)	After "C" Test: Change in Inductance (%)	After "C" Test: Change in Band Width or Q (%)
50-mc r-f transformer	XF-4226 ferrite	module element	2 1	20 (bw) --	2 5	20 (bw) --	0.8 5	24 (bw) --
50-mc mixer transformer	XF-4226 ferrite	module element	2 1	-- --	0.02 5	-- --	0.1 5	-- --
4.3-mc i-f transformer	XF-4226 ferrite	module element	0.09 +0.72 -0.90	20 (bw) --	0.09 10	20 (bw) --	0.09 10	20 (bw) --
	powdered iron	element	+0.21 -0.28	15 (Q)	8	10 (Q)	8	10 (Q)
4.3-mc limiter transformer	ferrite	module element	0.09 +0.72 -0.9	-- --	0.09 10	-- --	0.09 10	-- --
	powdered iron	element	+0.21 -0.28	15 (Q)	8	10 (Q)	8	10 (Q)
4.3-mc dis-criminator transformer	ferrite	module element	0.464 +0.72 -0.90	20 (bw) --	0.464 10	20 (bw) --	0.09 10	20 (bw) --
	powdered iron	element	+0.21 -0.28	15 (Q)	8	10 (Q)	8	10 (Q)

Inductor Type	Core Type		Change in Inductance Under Drive (%)*
4.3-mc dis-criminator transformer	powdered iron	module element	0.0464 +0.1

* At approximately 10 times the normal module-drive level.

TABLE 3.2.1-1 Comparison of Inductor and Micro-Module Specifications

3.2.2 DESCRIPTION OF PROGRESS

The first effort on the Initial Program for inductors included an investigation of the properties of magnetic materials and core configurations suitable for use in the Micro-Module. Commercially available ferrite and powdered-iron core materials were obtained and evaluated. Due to the small volume available in the Micro-Module for the coil, core materials having high permeability were generally desired. In addition, however, the stability requirements imposed by the module circuitry necessitated low, controlled temperature coefficients and Q's in the neighborhood of 100. Most of the materials investigated at this stage were deficient in at least one of these parameters. None of the available ferrite materials had usable temperature coefficients.

Among the configurations investigated were toroids, pot cores, cup cores, and E-core constructions. The requirements of the coil configuration included a need for self-shielding, low stray field, mechanical temperature stability, and adaptability to production assembly.

The toroidal configuration was selected since it is inherently self-shielding and contains no gaps to contribute stray field, or mechanical instability. The toroidal construction was also considered to be easily adaptable to the microelement wafer.

Since a coil suitable for mounting on a microelement wafer has a relatively small volume, it was felt that higher permeability matcrials than those available in powdered-iron cores would have to be produced in order to attain module performance requirements.

Initial experimentation conducted by the RCA Needham Plant indicated the possibility of controlling the temperature coefficients of ferrite cores to precise limits while maintaining higher permeability than that available in powdered-iron cores. The Needham Plant was thus funded to pursue this goal.

The initial work at Needham involved the doping of nickel-zinc ferrites with barium and cobalt additives to increase the frequency range. Cores made with these materials demonstrated Q's in excess of 100 for frequencies up to 100 mc and with permeability of approximately 10 for barium ferrite and approximately 50 for cobalt ferrite. The temperature coefficients were in the range of 0 ± 100 parts per million per ^{o}C for the barium ferrite and 3000 parts per million per ^{o}C for cobalt ferrite. To further improve the control of temperature coefficients a carbon-black additive was introduced. Barium was used to reduce the temperature coefficients of low-permeability cores while carbon-black was used for temperature coefficient improvements in high-permeability cores. Substantially lower coefficients for higher permeability material in the range of 0 ± 100 parts per million per ^{o}C were obtained on sample units having permeabilities of approximately 80. The effect of firing temperature and atmosphere on the temperature-coefficient performance of these cores was also determined. The particle sizc of the carbon-black was one of the controlling factors. Large particle size had the effect of lowering temperature coefficient but also reduced mechanical strength of the ferrite cores.

Effort at Needham was then channeled into three basic areas: Low frequency cores for frequency applications between 100 kc and 1 mc, medium-frequency cores for 1 to

10 mc, and high-frequency cores for 50 to 70 mc applications. The low-frequency cores were to have permeabilities in excess of 100 and temperature coefficients in the range of 300 parts per million per ^{o}C over the temperature range of -55°C to +85°C. The permeabilities of the medium-frequency ferrite cores were to be between 40 and 80 and the temperature coefficients, 0 $\pm$100 parts per million per °C. High-frequency cores were to have permeabilities in excess of 10 and temperature coefficients of 0 $\pm$100 parts per million per °C over the same temperature range.

Inductors for preliminary modules were designed to be wound on the early Needham ferrite cores. These designs included chokes ranging in inductance from 2.4 μH to 1500 μh as well as 4.3-mc I-F transformers and 50-mc R-F transformers. In addition a blocking-oscillator transformer was designed, permitting the incorporation of this previously separate component into the module. The ferrite cores used in these designs provided adequate performance for the room-temperature feasibility tests required of the preliminary modules.

The characteristics of ferrite cores developed for the prototype inductors were as follows:

a. <u>XF-3909-H</u> 50 mc

Q 100

μ . . . . 10 $\pm$10%

Temperature Coefficient . . . . -20 $\pm$50 ppm/°C

Max. $\frac{\Delta L}{L}$ between -55°C and +85°C 5%

Drive Sensitivity 0.09%

b. <u>XF-3893-5-130-131</u> 4.3 mc

Q 100

μ . . . . 56 $\pm$10%

Temperature Coefficient . . . . 0 $\pm$150 ppm/°C

Max. $\frac{\Delta L}{L}$ between -55°C and +85°C 5%

Drive Sensitivity* 0.8%

* Drive sensitivity was measured at 4.3 mc using a discriminator indicator. The input voltage was varied from 0.1 volt to 1 volt rms. The test coil inductance was 14 mH.

c. <u>XF-3988A-242</u> 2 mc

Q 55

μ . . . . 125 $\pm$10%

Temperature Coefficient . . . . 500 $\pm$300 ppm/^{o}C

Max. $\frac{\Delta L}{L}$ between -55^{o}C and +85^{o}C 3.6%

Drive Sensitivity* 0.8%

d. <u>XF-3732</u> 3.5 mc

Q 73

μ . . . . 210 $\pm$10%

Max. $\frac{\Delta L}{L}$ 90%

Drive Sensitivity* 2%

* Drive sensitivity was measured at 4.3 mc using a discriminator indicator. The input voltage was varied from 0.1 volt to 1 volt rms. The test coil inductance was 14 mH.

A total of 11 coil designs were made for prototype modules as indicated in Table 3.2.2-2

A subminiature toroidal coil winder was adapted to wind the small toroidal cores of the Micro-Module Program. The refinements made are described in Sections 3.1.3 and 3.2.3

This machine was capable of winding up to 300 turns of AWG 44 wire on the cores. Its wire size range covered AWG 38 to AWG 44.

At this stage the accurate measurement of parameters became of prime importance. The measurement of temperature-coefficient values with a high degree of accuracy required the development of special equipment. A description of this equipment is given in paragraph 3.2.3. The dynamic measurement of temperature characteristics made possible faster determination of temperature coefficients in the form of a continuous chart. Refinement of this measurement equipment took place over the period of approximately one year and its ultimate accuracy was established at $\pm$5 parts per million per ^{o}C as confirmed by the National Bureau of Standards.

A similar technique was used to determine drive sensitivity of ferrite cores. In this case the voltage level of the core was varied and the drift of the tuned circuit was

Micro-Module Type	Inductor Type	Frequency (mc) or Inductance (uH)
XM-14A	Choke	1500 μH
XM-15B	I-F Transformer R-F Choke	4.3 mc 38 μH
XM-16B	I-F Transformer R-F Choke	4.3 mc 38 μH
XM-17B	I-F Transformer I-F Transformer	4.3 mc 4.3 mc
XM-20B	R-F Transformer R-F Choke	50 mc 2.4 μH
XM-21B	R-F Transformer R-F Choke	50 mc 2.4 μH
XM-24A	Choke	600 μH
XM-28B	Pulse Transformer	
XM-29B	R-F Transformer R-F Choke	50 mc 2.4 μH

TABLE 3.2.2-2 Prototype Inductor Types

measured to indicate shift in inductance. Special permeameters were developed for these small-size cores to permit determination of permeability for selection purposes without the need for winding a coil on the core. Q measurements were made on a Boonton Q Meter after winding a test coil on the core. The measurement of prototype cores revealed the following basic problems:

a. Permeability shifts due to the stress caused by the encapsulant.

b. Permeability shifts due to induced polarized magnetic fields.

c. Temperature-coefficient shifts from both stresses caused by the encapsulant and magnetic fields.

The effect of encapsulation stress was reduced by coating the coils with a cushioning material such as silicon rubber or silicon resin prior to encapsulation, as described in Section 3.1.1.4

No solution other than magnetic shielding was found to prevent ferrite-core inductance changes due to polarized magnetic fields. Such fields could be introduced in the core either by an external magnetic force or by passing a direct current through one of the windings. Since the module was not expected to have unbalanced direct currents high enough to cause a polarized field problem, it was only necessary to insure that the

coils in modules were demagnetized after processing. This involved a cycle of demagnetization in a solenoid in conjunction with thermal cycling.

Measurements on prototype modules using the above cores indicated tuned circuit stabilities of approximately ± 20 kc in 4.3-mc I-F circuits. This stability was not considered adequate for final-grade modules and led to a reopening of temperature-coefficient studies by Needham. Substantial reductions in temperature coefficients and its tolerance were attempted by more precise control of the percentage of additives, firing temperature and atmosphere, and time.

Tuned circuit stability attained in the final-grade modules with ferrite cores was ± 12 kc in the 4.3-mc I-F circuits. At this time, however, the subassembly requirements for modules had been more closely determined indicating a need for a stability of $\pm$ 4 kc in the 4.3-mc I-F circuits. In reassessing the capabilities of ferrite cores it was determined that little further improvement in temperature coefficients could be expected. In addition the improvement in temperature coefficients had been realized through a gradual reduction of permeability to approximately 8 to 10. It was then apparent that this represented little advantage over available powdered-iron cores having similar permeability at 4.3 mc. A parallel program was started under Program Extension I to establish sources and evaluate suitable powdered-iron cores meeting the program size and stability objectives. After approximately one third of the final-grade modules were built, these cores became available and it was decided that the balance of the inductors for i-f modules would be built with powdered-iron cores. Stability obtained with these cores is as follows:

Temperature coefficient	25 ± 10 ppm/^{o}C
Drive sensitivity	0.1% (when subjected to 0 to 30 Oersteds)

Module stability attained with these cores was in the neighborhood of ± 7.5 kc deviation from 4.3-mc.

Acceptance tests were performed on final-grade cores and coils, including environmental and life tests in encapsulated modules. The results of these tests, described in Section 3.3.5 of this report, were accepted on the Initial Program. All test samples and required deliveries were completed, satisfying the requirements of the design plan.

3.2.3 DESIGN AND CONSTRUCTION OF SPECIAL EQUIPMENT

3.2.3.1 WINDING MACHINE

The Micro-Module requirement of selecting an existing form of flat, radially terminated, self shielding, lumped inductance led to the selection of the toroid. Existing toroid-winding techniques were investigated and available commercial winding-machine designs were reviewed before RCA purchased a Boesch Model SM miniature toroidal coil winder.

In order to wind toroids of few turns (for R-F coils) RCA developed a new type of shuttle which could be opened to deliver a finished coil without disturbing the remaining load. Consequently, reloading for each unit was unnecessary. Moreover, this shuttle was round in cross-section - the same shape as the hole in the toroid. This method appeared desirable for winding R-F coils on 0.200-inch cores, which fit on the microelement substrate, and the Boesch Model SM was modified to drive the hypodermic stock stuffed shuttle used in this winding system.

A core-speed indicator was added to provide improved resettability at the slow speeds required by bank winding. The original loader, designed for this shuttle by RCA, spiraled the magnet wire from a flatted and tapered mandrel having a pusher which moved the spiral through a funneling block and into a hypodermic stock shuttle held in position on the other side of the block. When the spiral was all the way through the shuttle, it was cut by a guillotine at the funneling block. The nozzle was then hand threaded onto the straightened end of the wire and guided into the end of the shuttle. The opposite end of the shuttle was slotted toward the shuttle center to permit dispensing the wire when the ends were coupled by the nozzle. The original shuttles were formed from 0.035-inch diameter stock and used very tiny stainless-steel nozzles that were easily lost in the threading operation.

The first coils wound with the above setup were wound with AWG 40 H.F. wire through an 0.007-inch jewelers-drill nozzle hole. This combination provided adequate tension but visably scraped the wire and produced shorted turns.

A switch to a Nylon nozzle improved the scraping to a point where shorted turns disappeared and the first I-F transformers and chokes could be produced. Magnet-wire abuse, as monitored by exposed copper in an electrolytic bath, continued to be a major problem. Having produced predictable but unsatisfactory coil parameters, the program now required the use of both larger and smaller wire sizes. AWG 38 wire could be wound, but the shuttle buckled badly and spiraling mandrel breakage occurred. On the smaller side, AWG 42 wound satisfactorily but tension of AWG 44 were so low that a coil-spring type of winding resulted which would slide loosely about the core. The demand for larger wire (AWG 38) resulted in increasing the shuttle size to 0.049-inch diameter. This shuttle with a Nylon nozzle loaded from an 0.015-inch-diameter mandrel produced a small percentage of coils without any exposed copper. Increased tension for winding AWG 44 wire was provided by the larger spiral and a smaller nozzle hole. This combination of mandrel, shuttle and nozzle produced some usable coils for all program requirements. Coils were wound by this system while other winding developments took form.

Although both a continuous (friction) core drive and a segment-winder core drive were purchased with the original Boesch Model SM, the latter was never used since it gripped the toroid over a considerable area leaving only about 215° on which to wind. The friction drive offered full toroid winding length and the original design intent was to start secondaries from one end of the primary. This failed to produce the desired coupling and the coils were redesigned to move the secondary into the center of primary. The new design produced close coupling but poor uniformity as the coupling varied with the secondary location relative to the primary. Two inovations were made to accurately locate the start of the secondary from the end of the primary. The first involved counting the shuttle turns as the coil was idled into the start position.

The second used an indicator geared directly to the core-drive pulley. Both failed because of variable friction in the core drive. The use of Teflon coated cores aggravated this condition as the low-friction Teflon caused excessive slip, and when the drive tension was increased, the rounded edges (cores were tumbled) permitted the core to ride up on the drive. This difficulty further stimulated interest in segment winders and a design was started to provide a core vise which would permit windings on up to 330° of the toroid.

While the early coil design was taking place, work on machine refinement was being done by Boesch Manufacturing Company. Boesch designed a loader attachment to start the load spiral so that it searched its own way through a nozzle permanently attached to the end of the shuttle. This refinement proved to be important production break-through since it eliminated the tedious nozzle-threading operation and the lost nozzle and permitted effective honing of the metal nozzle which remained in place relative to the winding plane. Previously, a new metal nozzle could not be adequately honed before it was lost. The return to the metal nozzle provided much needed tension for winding AWG 44 wire and a stronger rigid shuttle. The Boesch loader design also provided a color-coded selection of loader attachments providing optimum setups for each of four shuttle diameters, 0.028, 0.035, 0.050 and 0.062 inch, all of which could be driven by their revamped winding machine, commercially titled the Monitor. RCA purchased the first Monitor with Micro-Module inductor refinements and continued to suggest further machine refinements. During this stage, an improved spiraling mandrel, with less tendency to damage magnet wire and with an improved life span, was designed.

The latest improvement to be made in the winding machine was the birdbeak segment winder, a joint effort of RCA and Boesch. The core vise in this assembly grips the core adequately but still provides 325° for the winding. The turret permits easy indexing and relocating to ±5°. Back windings made with this core holder are less random and more reproducible than those made with the friction core drive. Moreover, the coil is more easily accessible for twisting taps and lead preparation.

The present RCA winder (Figure 3.2.3-1), using only one loading mandrel, with one diameter of shuttle and only two nozzle-hole sizes, has proven adequate for winding the present five R-F choke designs, the present six R-F transformer designs and a blocking-oscillator transformer design included in the initial program. Complete Boesch accessories should make the winder more versatile. Time study has indicated that the present winder is equal or superior to machines winding larger toroids. An automatic stop on the loader permits the operator to wind during loading time, thus reducing the production time. This is impossible on the slider-type shuttle, where the wire must be loaded on the winding machine.

3.2.3.2 TEST JIGS

Figures 3.2.3-2 and 3.2.3-3 illustrate the special test fixtures used to simplify the test and handling procedures for unmounted and mounted coils, respectively.

In the design of these special test fixtures, an effort has been made to adopt microelement test techniques to standard commercial test equipment. Figure 3.2.3-4 shows a

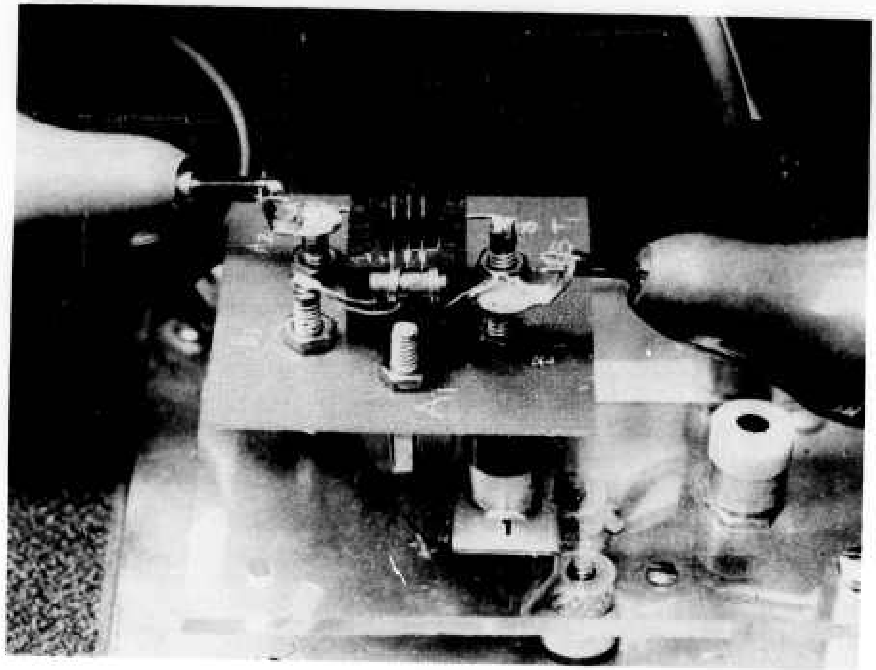

FIGURE 3.2.3-1 Toroidal-Coil Winder and Shuttle Loader

dynamic test setup for measuring of unmounted transformers. A Boonton Radio Company Model 250A RX Meter and two Ballantine R-F voltmeters perform the test functions and an adaptor fixture is used to connect the microelement to the test equipment.

3.2.3.3 TEMPERATURE-COEFFICIENT-MEASURING EQUIPMENT

Test equipment for measuring temperature coefficient of inductance was designed and built. The basic operation of the equipment is shown in the block diagram Figure 3.2.3-5. The toroidal inductor to be tested is connected in an oscillator tank circuit. The test oscillator receives its feedback over several buffer shapes. The use of automatic gain control avoids frequency shifts caused by the Miller effect in the oscillator tube. The oscillator signal is mixed with a signal derived from a crystal-controlled standard generator, and the beat frequency is then fed to a frequency meter, which provides the voltage for the Y-deflection of an X-Y recorder. The X-axis of the recorder is operated directly from a temperature-sensitive element placed in the temperature box. The recorder registers frequency deviation as a function of temperature. For small deviations, the inductance change is approximately linear with frequency change as shown by the following expression:

$$\frac{\Delta L}{L} = \frac{2 \Delta F}{F}$$

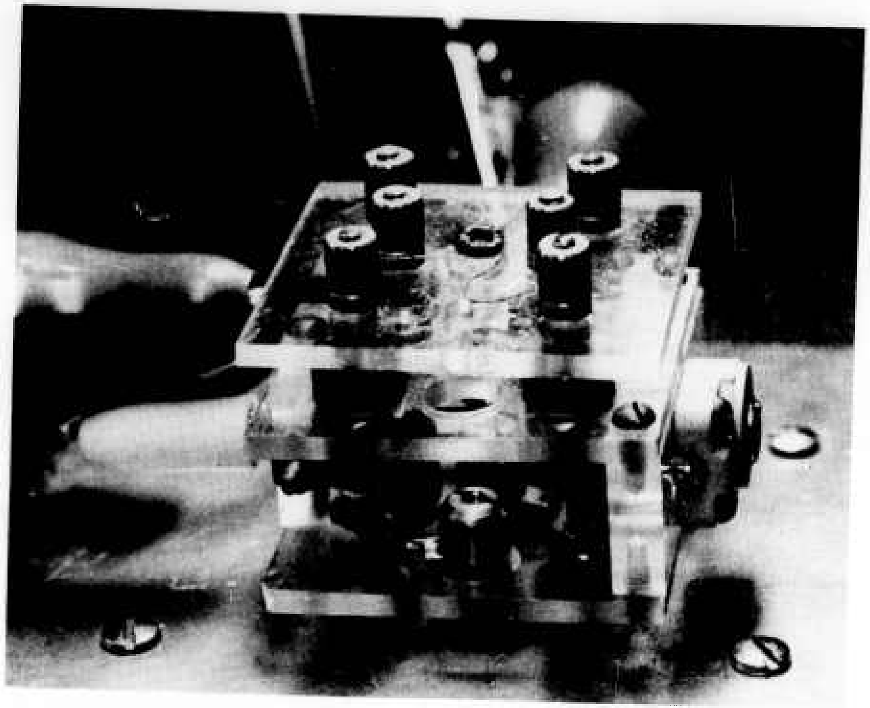

FIGURE 3.2.3-2 Test Jig for Unmounted Coils

FIGURE 3.2.3-3 Test Jig for Mounted Coils

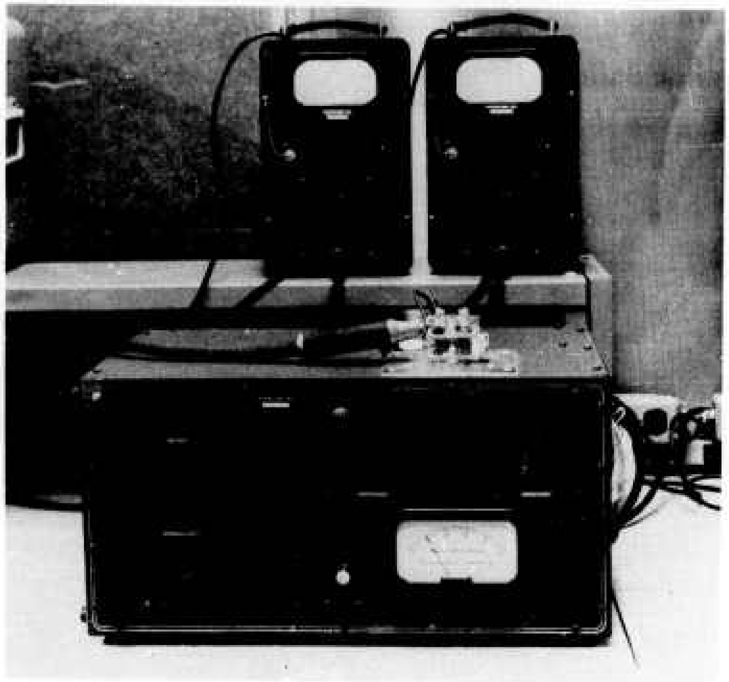

FIGURE 3.2.3-4 Dynamic Test Setup for Unmounted Transformers

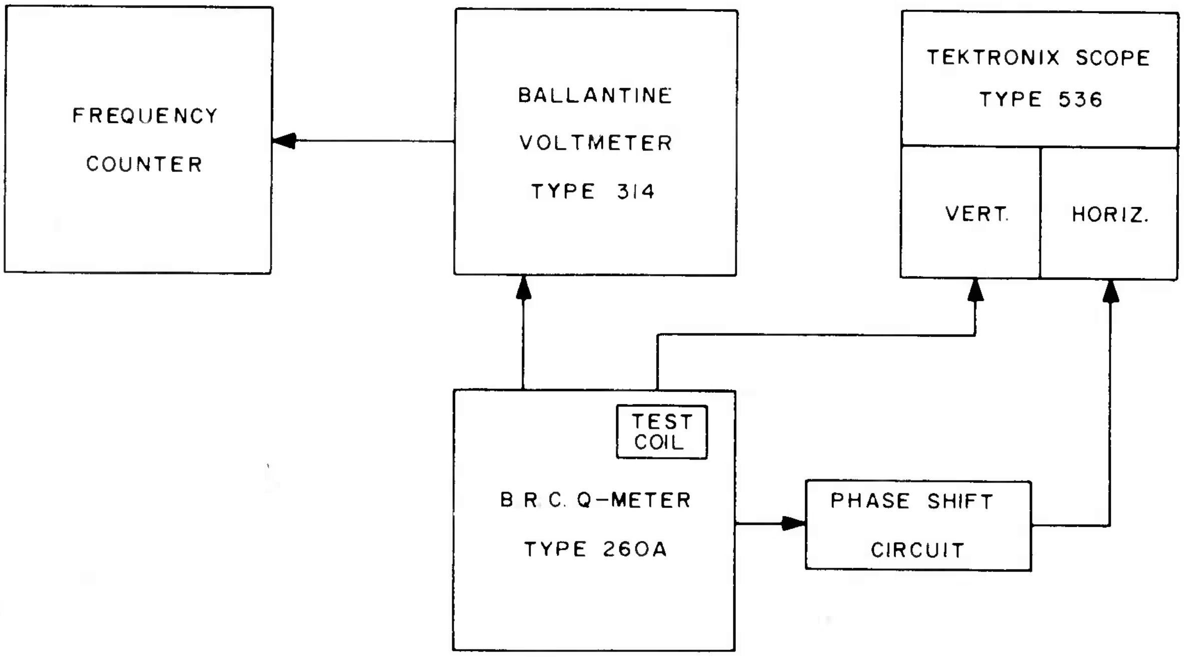

FIGURE 3.2.3-5 Drive Sensitivity Measuring Equipment, Block Diagram

For convenience, an operating frequency of 2 mc was chosen to allow a direct conversion from frequency deviation in cycles per second to inductance deviation in parts per million. Measurement can also be made at other frequencies.

The temperature box contains a heater elcment and a nozzle for injecting liquid carbon dioxide and permits temperature variation over a range from -55 to +95°C.

3.3 DESCRIPTION OF TESTS, AND PERFORMANCE DATA

Inductor testing was divided into four main areas as follows:

a. Core testing

b. Prototype induetor evaluation testing

c. Final-grade inductor acceptance test

d. Testing of final inductor elements for delivery and for modules

The core-test program was conducted in conjunction with the ferrite-core improvement effort by RCA, Needham, Mass. The types of tests performed and final results are indicated. A large number of the final R-F transformers were built with powdered-iron cores because final eircuit stability needs could not be met with the state-of-the-art ferrite. Powdered-iron-core performanee is not covered in this report; it will be ineluded in later reports under Program Extension I.

The prototype-test program was conducted to assess the performance of induetor elements which used the materials and techniques selected for final designs. While the prototype microelements were not required to meet environmental and life-test requirements, they were tested under these conditions to determine their potential. These latter tests were made with the inductor encapsulated in the module structure. The prototype inductor data given in this seetion summarize results of the various tests.

Final-aceeptance-test results are given in summary covering performance of the various chokes and transformers against all Micro-Module specifieation objectives. The inductors tested were constructed with materials and techniques used for the coils built into the final Micro-Modules. Environmental and life tests were performed on inductors which were assembled and encapsulated in the module structure.

Also included in this section are charts indicating typical data for each of the choke and transformer types used in final Micro-Modules or shipped as microelements to the Signal Corps.

Microelement inductors are manufactured in two basic stages: wound inductors and mounted inductors. Various tests are performed in order to insure conformity to specifications and required quality levels at each manufacturing level.

Certain electrical tests are performed on unmounted transformers because of their complex nature and because transformers are usually mounted on capacitor substrates, which are difficult to salvage. Tests performed include measurement of static parameters and dynamic performance, whichever is applicable. Performance Test equipment is shown in Figure 3.3.1-1.

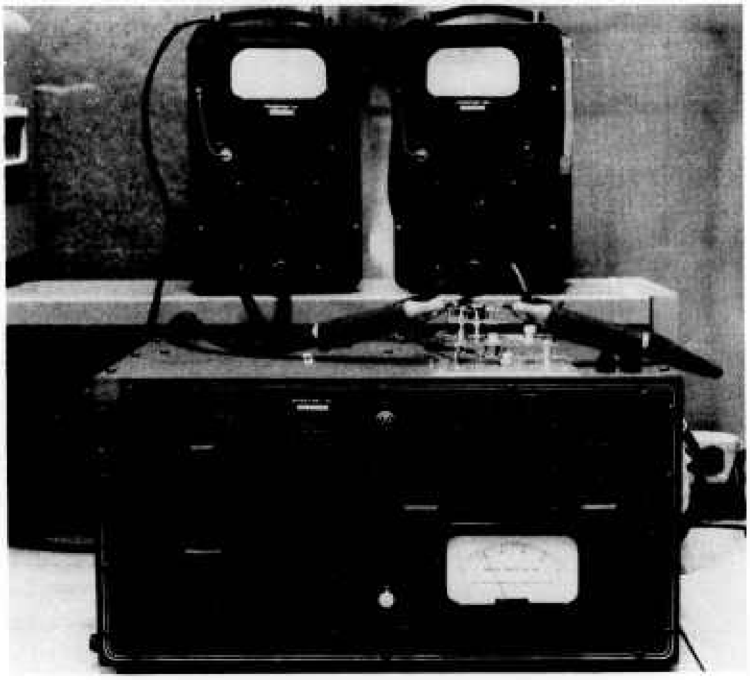

FIGURE 3.3.1-1 Test Equipment used for Performance Tests on Microelement Inductors

3.3.1 GENERAL DESCRIPTION AND PURPOSE OF TESTS

3.3.1.1 CORES

Measurements on ferrite cores included the following:

- Permeability
- Losses or Q
- Temperature coefficient
- Curie temperature
- Drive sensitivity
- Remanence
- Mechanical uniformity

3.3.1.2 CHOKES

Performance Test	Purpose of Test
1. Inductance	Check for correct number of turns and winding pitch.
2. Q	Check on initial coil Q, winding configuration, effects of impregnant, mounting & soldering.
3. Self-resonant freq.	To establish compatibility of inductance and substrate assembly to meet module circuit requirements.

3.3.1.3 R-F AND I-F TRANSFORMERS

Performance Test	
1. Inductance	Check for correct number of turns and winding pitch.
2. Qe, Qu, Ql	Check on initial coil Q, winding configuration, effects of impregnant, soldering and effect of proximity of transformer windings to capacitor substrate.
3. Input Impedance Bandwidth	To insure circuit requirements are met under simulated loaded-module conditions. Proof of correct number of turns and coefficient of coupling.
4. Insertion Loss	To indicate general transformer efficiency under loaded-circuit conditions.
5. Resonance	To insure compatibility of transformer inductance with substrate wafer capacitance to provide required frequency tuning adjustment range.
6. Voltage Ratio	To establish whether specified number of turns have been applied to transformer.
7. Insulation Resistance and Dielectric Strength	To verify resistive isolation between primary and secondary windings and all electrically insulated substrate wafer terminations.

3.3.1.4 PULSE TRANSFORMERS

Inductance & Q	Correct turns and shorted turns.
Coupling Coupling ratio	Placement and uniformity of windings
Insulation resistance and dielectric strength	To prove resistive isolation between windings and insulated termination notches.
Dynamic pulse test	Demonstrate required module performance relating pulse width, rise time, overshoot and output.

Test results are described in the following sections.

3.3.2 FERRITE CORE TESTS

Some of the basic characteristics of the coils made with ferrite cores are indicated in Table 3.3.2-1. Plots of the output voltage vs. temperature for the ferrite cores are shown in the Curie Diagrams of Figure 3.3.2-1. In these plots, the Curie point is considered to be the temperature at which the output voltage is reduced to 10 per cent of the peak voltage. None of the Curie points fall below 240°C.

CORE No.	FREQUENCY	MINIMUM Q	NOMINAL μ	TEMPERATURE COEFFICIENT	CURIE POINT
XF-3732	4.3	70	200	3000 ppm/°C	240°C
XF-3846	4.3	100	50	220 $\pm$220 ppm/°C	310°C
XF-3909	50	100	10	0 $\pm$50 ppm/°C	380°C
XF-3988	4.3	40	125	470 $\pm$470 ppm°C	240°C
XF-4226	25	100	10	-100 $\pm$70 ppm/°C	--
XF-3843	4.5	90	24	300 $\pm$500 ppm/°C	--

TABLE 3.3.2-1 Basic Characteristics of Ferrite Cores

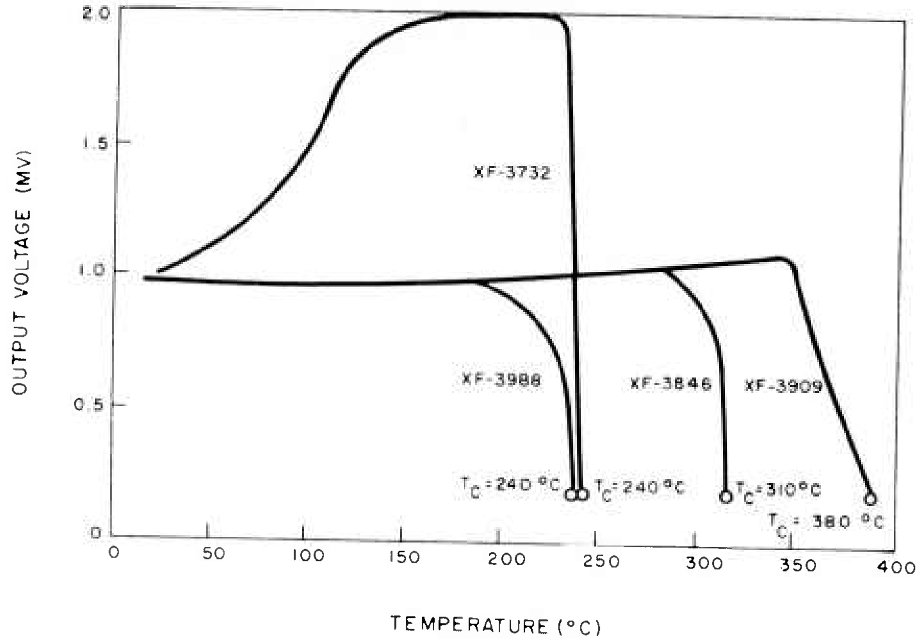

FIGURE 3.3.2-1 Curie Points of Four Different Ferrite-Core Materials

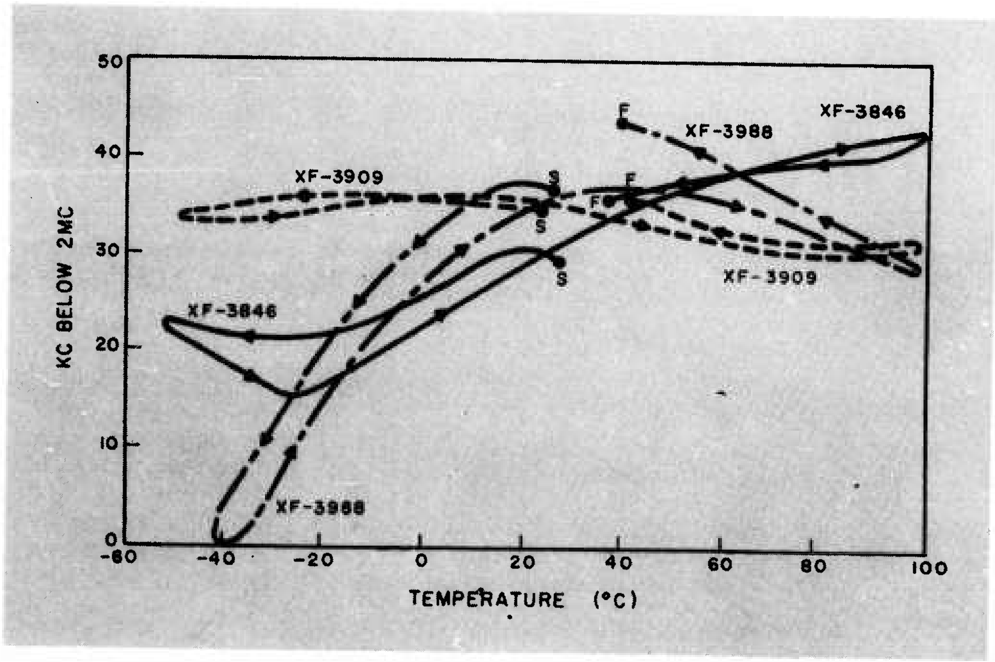

FIGURE 3.3.2-2 Temperature-Coefficient Plots of Three Ferrite Cores

A typical temperature-coefficient plot for three coated and encapsulated ferrite cores wound with test windings is shown in Figure 3.3.2-2. These tests were made on the dynamic-curve tracer described earlier in the report.

A summary of the mechanical properties of the various ferrite cores used in the program and the powdered iron core used in the later final-grade I-F transformers are indicated in Table 3.3.2-2.

Mechanical Uniformity Data

FERRITE CORES	O.D.		I.D.		HEIGHT	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
XF-4226 Spec Values	.220 .219 -	.226 .229	.109 .108 -	.113 .118	.0512 .048 -	.0535 .058
XF-3843 Spec Values	.224 .217 -	.227 .231	.111 .107 -	.113 .117	.0494 .043 -	.0518 .058
XF-3988	.209 .208 -	.216 .218	.107 .106 -	.112 .116	.0470 .044 -	.0493 .054
POWDERED IRON						
57-3788-12 Spec Values	.197 .190 -	.202 .210	.100 .100 -	.104 .105	.0469 .048 -	.0525 .052

TABLE 3.3.2-2 Mechanical Data for Ferrite and Powdered-Iron Cores

The variances noted between ferrite-core dimensions result from the fact that the same molds were used for each formulation. Varying shrinkage rates thus account for the variance.

Ferrite-core drive sensitivity was determined in a discriminator setup, such as the one shown in Figure 3.3.2-3A, thus, simulating the actual working conditions of the 4.3-mc discriminator in the AN/PRC-36 equipment. The afc voltage was kept at zero balance by changing the frequency for different input voltage settings. The variation of the frequency was an indication of the change of inductance due to drive changes, as demonstrated in Figure 3.3.2-3B. Drive sensitivity was measured at 4.3 mc with a discriminator indicator. The input voltage was varied from 0.1 volt to 1.0 volt rms. Test-coil inductance was 14 μh.

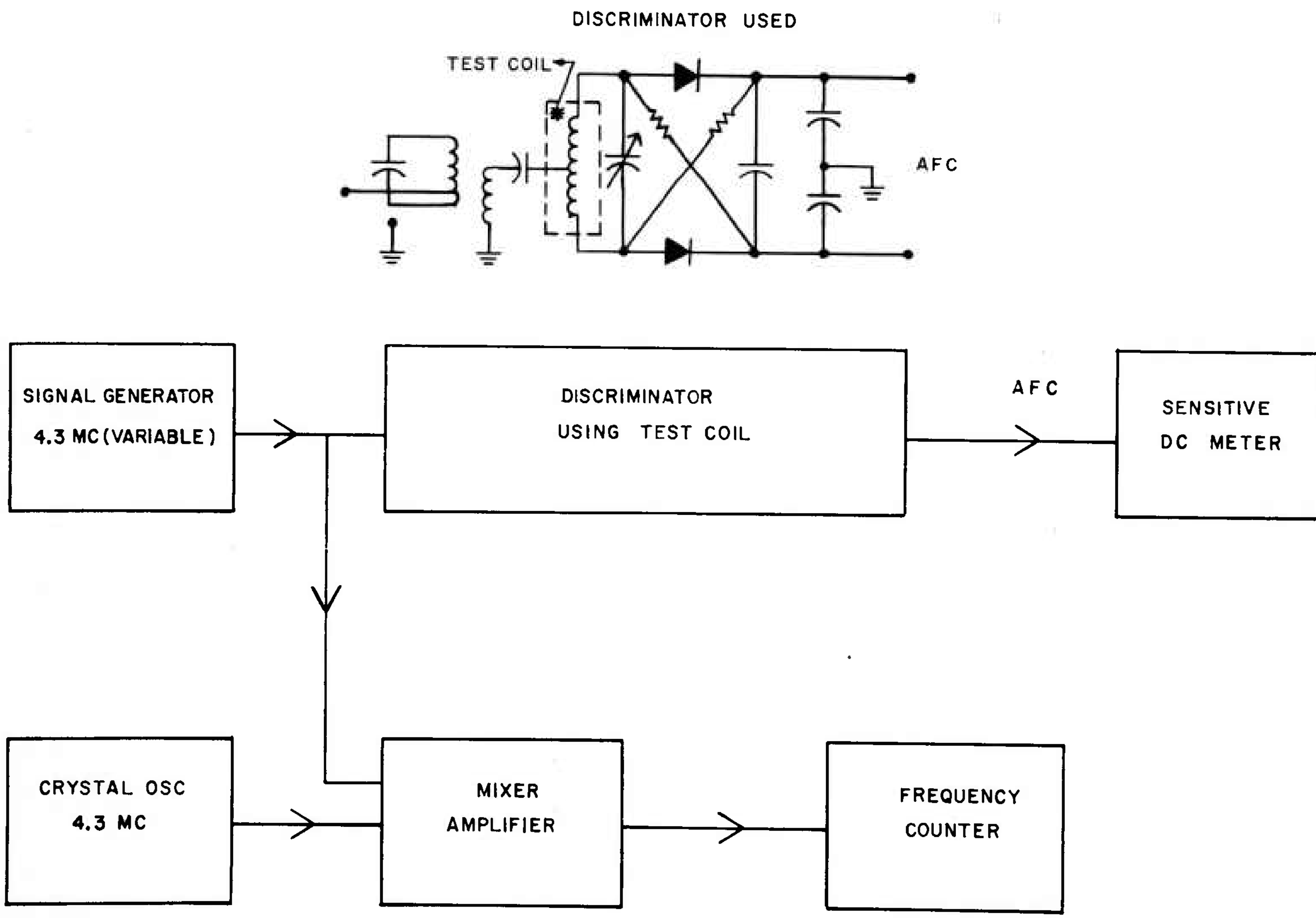

FIGURE 3.3.2-3A Test Setup used for Ferrite Drive-Sensitivity Tests

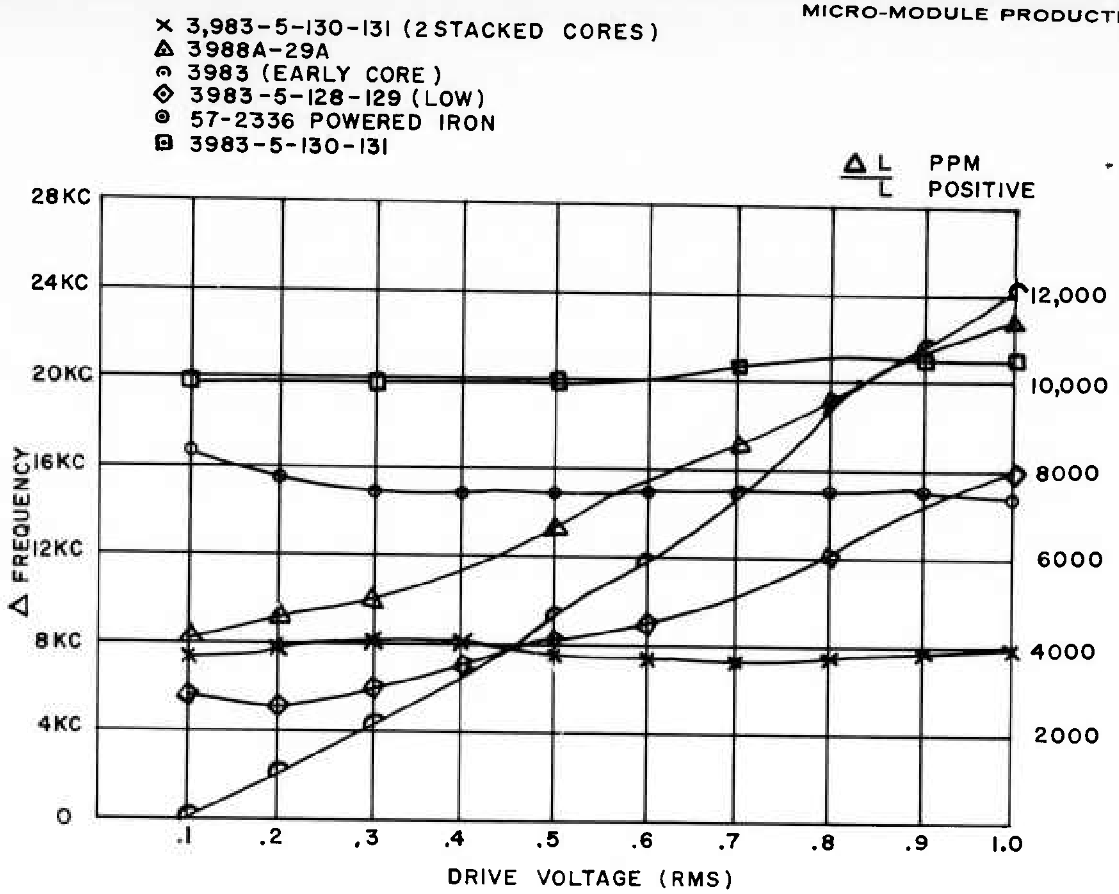

FIGURE 3.3.2-3B Drive-Sensitivity Characteristics of Toroids

The effects of ferrite remanence have been studied; the results are summarized in Table 3.3.2-3. The test was made after winding 300 turns on each ferrite core and pulsing the inductors with 100-volt pulses for a short time to assure saturation by the peak drive current. All cores showed considerable changes in inductance when measured with a Q meter both before and after pulse application. After pulsing, the cores exhibited very little change during a following three-hour period. Demagnetization returned the inductors to the original values. The pulsing used was more severe than normally is expected in the circuitry.

Core	Demagnetized	PULSE SENSITIVITY (μH)		Demagnetized
		Pulsed	Three Hours After Pulsing	
3988A-487	1700	1530	1530	1700
3988A-505	1650	1559	1550	1650
3983-5-130/131	845	780	780	849
3909 Box A	103.4	97	97.5	104
3732-2	2170	2090	2110	2170

TABLE 3.3.2-3 Magnetic Stability of Ferrite Cores

3.3.3 TEST PROCEDURES (Final-Grade Elements for Modules)

3.3.3.1 FIRST TEST ("A" TEST) UNMOUNTED INDUCTOR ELEMENTS

Chokes and Transformers

	Sampling
a. Mechanical inspection	
General visual and mechanical conformance with drawings	100%
Wire size	1%
Pitch uniformity	100%
Loose turns	100%
Lead length, stripping and tinning	100%
Loose turns	100%
Over-all thickness and diameter	100%
b. Electrical Tests	
Inductance and Q, primary and secondary	100%
Open circuit voltage (turns and coupling check)	100%

3.3.3.2 SECOND TEST "A" TEST MOUNTED MICROELEMENTS

Chokes

a. Visual and mechanical inspection	
General visual and mechanical and conformance to drawings and specifications	100%
Centering of inductor elements on substrate	100%
Impregnation and adherence of inductor element to substrate wafer	100%
Dressing of leads and solder connections	100%
Over-all thickness	100%
b. Elcctrical Tests	
Inductance at 1 } or attenuation at specified frequency for decoupling assemblies	100%
Self-resonant frequency } or attenuation at specified frequency for decoupling assemblies	100%

3.3.3.3 TRANSFORMERS

a. Mechanical Inspection

In general, the same mechanical inspection as that for chokes except that attention is focused on proper lead dress and conformance with assembly drawings. This is particularly applicable to high frequency transformers.

b. Electrical Tests

Resonant frequency	100%
Input impedance	5%
Bandwidth	5%
Insertion Loss	5%
Insulation resistance and dielectric strength	100%

c. Performance Values

Refer to B499277 Sheet 1 - Inductor performance Outline Specification and Dynamic Test Circuits: Microelement Inductors

d. Nominal Values and Limits, Electrical and Mechanical

Mechanical

Specifications for over-all thickness of unmounted inductors and mounted inductors. Inductor specifications describe mechanical requirements. Assembly drawings show the inductor position and orientation on the substrate and the points of lead breakout and their connections to wafer notches. These drawings provide a picture of the inductor assembly on a 10-to-1 scale.

Electrical

Electrical limits, based on circuit applications and the basic practical limits which can be expected through controlled manufacturing processes, were established for inductors.

The general details and procedures for reaching suitable electrical limits for inductors were as follows:

1. Choice of core material and wire size for the particular application.

2. Winding techniques which provide the most consistent mechanical characteristics.

3. The use of electrically nominal cores for initial samples.

4. Evaluation of initial samples for electrical characteristics and conformance with circuit-application requirements.

5. Nominal electrical values and limits were established on the basis of average values procured from initial samples.

6. Inductor standards with average electrical values were chosen.

7. Tentative inductor standard sheets were written up as test criteria for preliminary production quantities.

8. Final nominal electrical specifications and limits were established through the evaluation of inductors from an initial production quantity.

9. Applicable limits were specified on the following electrical parameters for R-F and I-F transformers and chokes:

   Inductance
   Q
   Bandwidth
   Resonance - tank and self-resonance
   Insertion Loss
   Reflected input impedance with specified loads

e. Transformer Input Impedance

Transformer input impedance was determined by direct measurement in RX bridge circuit. Measurement was accomplished by shorting out series resistor Ro by means of a shorting plug as shown in Figure 3.2.3-2 (closeup view of test fixture). Transformer primary tank circuit is tuned to center frequency (fc) by adjustment of trimmer located at right center of test fixture also shown on Photograph Figure 3.2.3-2.

f. Bandwidth

Bandwidth is measured by opening the shunt which places Ro in series with the transformer primary tap. The 250A RX meter is then used as a signal generator, Ro simulating as the output impedance of the previous module - I-F stage. The two Balantine R-F voltmeters are used to measure input-and output-signal levels (Ein and Eout) and to monitor output while varying the frequency for response curve measurements. Output of the RX meter is also monitored with a Hewlett-Packard Model 524B frequency counter for accurate bandwidth measurement results. This system of measuring bandwidth provides measurement accuracy and repeatability of approximately ±2%.

g. Insertion Loss

Insertion loss at resonance is calculated by use of the following formulae and values derived from tests made concurrently with bandwidth measurement.

$$IL_{db} = 20 \text{ Log} \frac{VIN}{VOUT} - 10 \text{ LOG } \frac{RIN}{RL}$$

IL - power insertion loss in db

RIN - direct measured value of input impedance at primary tap

RL - load impedance

VIN - input volts at primary tap

VOUT - output volts across RL

3.3.4 PROTOTYPE TEST PROGRAM

The prototype test program was conducted on a total of sixty-nine (69) microelements representing a cross section of the inductor types required for modules.

An analysis of the A-test data is given in Table 3.3.4-1 indicating shifts in parameters after assembly and encapsulation.

A total of twenty-four (24) inductor microelements were submitted to environmental (Group B) tests as indicated in Table 3.3.4-2 and Table 3.3.4-3. The microelements were assembled in the module structure and encapsulated prior to B tests.

Life tests (Group C) were performed on twenty (20) microelements as indicated in Tables 3.3.4-4 and 3.3.4-5. These units were also assembled in the module structure and encapsulated.

The results of prototype tests indicated some difficulty in obtaining adequate encapsulation. The majority of failures were due to reduced insulation resistance between riser wires, while the inductors in general gave good electrical performance. The only failures on the final acceptance test program occurred in moisture resistance test and were contributions by encapsulation defects.

GROUP	No. OF ELEMENTS	ENCAPSULANT (Stycast)	RESISTANCE CHANGE (%)		EFFECTIVE INDUCTANCE CHANGE (%)		EFFECTIVE Q CHANGE (%)		CHANGE IN SELF RESONANT FREQUENCY (%)		CHANGE IN 1 KC INDUCTANCE (%)	
			A	B	A	B	A	B	A	B	A	B
7	4	2651	-13.3	0	+31.5	+13.2	-28.5	-32.1	-18.1	+3.6	--	+9.3
8	2	2651-40	-14.4	0	+11.3	+4.0	-15.4	-22.2	-7.3	+1.2	--	+3.8
9	4	2651-40	-9.1	0	+1.1	+2.2	+1.5	-4.1	+4.3	+0.2	+1.9	+0.2

GROUP	No. of ELEMENTS	CHANGE IN VOLTAGE GAIN		INSULATION RESISTANCE (1000 meg-ohms min.)		DIELECTRIC STRENGTH (At 100 v dc)	
		A	B	A	B	A	B
7	4	--	-9.9% -0.755 db	ok	ok	ok	ok
8	2	--	-6.4% -0.625 db	ok	ok	ok	ok
		INSERTION LOSS					
9	4	+3.6% +0.28db	-0.9% -0.07% db	ok	ok	ok	ok

GROUP	No. OF ELEMENTS	TEMPERATURE COEFFICIENT (PPM/°C)		CHANGE IN REFLECTED INPUT IMPEDANCE (%)		CHANGE IN TUNED FREQUENCY (%)	
		A	B	A	B	A	B
9	4	-21 ±11	-20 ±10	-2.8	-0.7	0	-1.2

TABLE 3.3.4-1 Analysis of "A"-Test Data, Prototype Inductors

GROUP	No. OF ELEMENTS	ENCAPSULANT (Stycast)	RESISTANCE CHANGE (%)		EFFECTIVE INDUCTANCE CHANGE (%)		EFFECTIVE Q CHANGE (%)		CHANGE IN SELF RESONANT FREQUENCY (%)		CHANGE IN 1 KC INDUCTANCE (%)	
			A	B	A	B	A	B	A	B	A	B
1	4	2651	+5.2	-0.3	-0.5	+0.1	-19.	+2.2	--	+10.	+2.0	+22.
1	4	2651	0	0	-0.4	-1.5	-3.2	+5.0	--	-9.5	+3.3	+22.8
2	8	2651-40	+2.7	-2.1	0	+0.2	-3.0	+1.7	-0.6	0	+2.7	-2.1
3	4	2651	--	+19.	-2.9	+3.7	+4.9	-1.8	- -	+2.8	--	+15.
4	4	2651-40	+3.2	-5.1	+2.1	-6.2	+8.2*	+11.6	+0.6	-0.2	+3.2	-5.1
4	4	2651-40	+2.5	-1.8	-0.8	+0.3	-3.5	+3.2	+3.9	-1.8	+2.5	-1.8
6	4	2651-40	+0.8	-0.3	+0.8	+0.2	-0.7	+1.6	-5.2	+1.8	+0.9	+1.5
6	4	2651-40	+1.6	-1.1	+0.3	+1.9	+0.7	+0.2	0	+0.3	-5.9	+7.5

TABLE 3.3.4-2 Analysis of Moisture-Resistance "B"-Test Results for Prototype Inductors (Sheet 1)

GROUP	No. OF ELEMENTS	INSULATION RESISTANCE (1000 megohms min.) AND DIELECTRIC STRENGTH (At 100 v dc)		OVERLOAD (At 20 ma dc)
		A	B	A and B
1	4	Failed	Failed	ok
1	4	Failed	Failed	ok
2	8	ok	ok	ok
3	4	Failed**	ok**	ok
4	4	2 Failed 2 ok	2 Failed 2 ok	ok
4	4	ok	ok	ok
6	4	ok	ok	ok
6	4	ok	ok	ok

A. Within two hours after removal from moisture test.

B. After 24-hour drying after removal from moisture test.

1. All changes in inductance and Q are based on effective values, uncorrected for distributed capacitance.

2. ** These elements failed the insulation-resistance and dielectric-strength checks within two hours after removal from moisture test, but recovered and passed these checks after the 24-hour-drying period.

3. * The Q of this module increased 3.5 per cent after shock test and decreased 15.6 per cent after immersion.

4. A dashed line indicates that no measurement was made.

5. The total change is the sum of the changes noted in readings A and B.

TABLE 3.3.4-2 Analysis of Moisture-Resistance "B"-Test Results for Prototype Inductors (Sheet 2)

GROUP	ELEMENT AND TEST MODULE	"A" TEST	"B" TEST	"C" TEST (d)
	INDUCTORS			
1	Inductor XF-4226 2651 Encapsulant 4 Modules (16 Coils)	16 elements 14 passed 2 shorted (a)	8 elements 8 passed (b)	6 elements 4 passed 1 shorted 1 failed (c)
2	Inductor XF-4226 2651-40 Encapsulant 2 Modules (8 Coils)	8 elements 8 passed	8 elements 8 passed	
3	Inductor XF-3988 2651 Encapsulant 3 Modules (12 Coils)	12 elements 12 passed	4 elements 4 passed (b)	8 elements 8 passed
4	Inductor XF-3988 2651-40 Encapsulant 2 Modules (8 Coils)	8 elements 8 passed	8 elements 6 passed 2 passed (b)	
5	Inductor XF-3843 2651 Encapsulant 1 Module (4 Coils)	4 elements 4 passed		4 elements 4 passed
6	Inductor XF-3843 2651-40 Encapsulant 2 Modules (8 Coils)	8 elements 8 passed	8 elements 8 passed	
	TRANSFORMERS			
7	50 MC Transformer XF-4226 2651 Encapsulant 4 Modules (4 Transformers)	4 elements 4 passed		2 elements 2 passed
8	50 MC Transformer XF-4226 2651-40 Encapsulant 2 Modules (2 Transformers)	2 elements 2 passed		
9	4.3 MC Transformer XF-4226 2651-40 Encapsulant 4 Modules (4 Transformers)	4 elements 4 passed		
10	Pulse Transformer XF-3988 2651-40 Encapsulant 4 Modules (4 Transformers)	4 elements 4 passed		

a. Shorted after encapsulation.

b. Coils passed. Encapsulant failed insulation-resistance measurement after moisture-resistance test.

c. Failed insulation-resistance measurement.

d. All "C"-test results are preliminary. A complete evaluation and analysis is being prepared.

TABLE 3.3.4-3 Results of Inductor Prototype Test Program

GROUP	No. OF ELEMENTS	CORE MATERIAL	EFFECTIVE INDUCTANCE CHANGE (%) A	EFFECTIVE INDUCTANCE CHANGE (%) B	EFFECTIVE Q CHANGE (%) A	EFFECTIVE Q CHANGE (%) B	CHANGE IN SELF RESONANT FREQUENCY (%) A	TEMPERATURE COEFFICIENT (PPM/°C)	INSULATION RESISTANCE A	DIELECTRIC STRENGTH (At 100 v dc) A	OVERALL RESULT
1	1	XF-4226	(intermittent coil after 1700 hours of life test)						ok	ok	failed
	1	XF-4226	-0.5	-5	-16	-7	-2.7	in test	x	x	ok (C)
	3	XF-4226	+2.	+8.3	-2	-2.7	+2	in test	ok	ok	ok
	1	XF-4226	+10	+9	-2	-4	-0.3	in test	ok	ok	ok
3	1	XF-3988	-3.1	+2.1	+10	-9.3	+12	in test	ok	ok	ok
	1	XF-3988	+2.1	-1.5	-3.1	+4.9	+10	in test	ok	ok	ok
	6	XF-3988	-19	+24	+14	-12	+4.5	in test	ok	ok	ok
5	4	XF-3843	-18	+34	+2.1	-4.9	-28	in test	ok	ok	ok

A. After 2000-hour life test at 85°C and 10 ma dc.
B. After demagnetizing in direction parallel to riser wires.
C. Inductive element passed. Insulation resistance to adjacent riser wire failed.

TABLE 3.3.4-4 Analysis of "C"-Test Results for Prototype Inductors

GROUP	No. OF ELEMENTS	CORE MATERIAL	EFFECTIVE INDUCTANCE CHANGE (%)		EFFECTIVE CHANGE IN UNLOADED Q (%)		CHANGE IN UNLOADED 3-DB BAND-WIDTH (%)		INSULATION RESISTANCE	DIELECTRIC STRENGTH (At 100 v dc)	OVERALL RESULT
			A	B	A	B	A	B	A	A	
7	1	XF-4226	-6.7	+6.0	+23	-18	-19	+22	ok	ok	ok
7	1	XF-4226	-8.8	+8.0	+5.7	-4.7	-6.7	+5.1	ok	ok	ok

A. After 200-hour load-life test.
B. After demagnetization in direction parallel to riser wires.
C. Both modules encapsulated with Stycast 2651.
D. Measurement frequencies - 50 and 70 mc.

TABLE 3.3.4-5 Analysis of "C"-Test Results for Prototype Transformers

3.3.5 FINAL ACCEPTANCE-TEST DATA

Final Acceptance Tests were performed on two values of final-grade inductor chokes representing the two most active ferrite core types -- XF-3988 and XF-3843.

Eighty each final-grade test elements were prepared with inductance values of 350uH and 38uH and were subjected to Group A tests. Subsequent to this, these groups were subdivided into groups for Group B environmental tests and Group C load life tests. The subgroup quantities were twelve and sixty-eight of each type test element, respectively. Results are shown in Table 3.3.5-1.

No tests were performed on ferrite cored I-F transformers as originally scheduled in the final acceptance program due to the fact that powdered iron cores were substituted for the ferrite cores.

Summaries of test data from A, B, and C tests are presented in Tables 3.3.5-2, 3 and 4.

The results of the "A", "B" and "C" tests were satisfactory until moisture resistance test. After moisture resistance test several units failed in respect to insulation resistance between riser wires. These failures were attributed to poor encapsulation.

3.3.6 FINAL MICROELEMENTS FOR MODULES AND DELIVERY TO SIGNAL CORPS

Typical initial performance of the various types of final-inductors and transformers are tabulated in this section. The data given were measured on a total of 200 components consisting of 12 different inductor and transformer types delivered as final microelements to the Signal Corps, as required under Item 6A of Design Plan MMDP-3.

Table 3.3.6-1 describes the performance of the various chokes used in the program. All of these chokes are based on ferrite core designs and are generally not critical from a stability standpoint.

The transformer microelement performance is shown in Table 3.3.6-2. All of the types described are based on ferrite cores.

The pulse transformer performance is indicated in Table 3.3.6-3.

All inductors for delivery to the Signal Corps passed the applicable "A" tests.

GROUP No.	ELEMENT TYPE	No. OF ELEMENTS	RESULTS OF "A" TEST	RESULTS OF "B" TEST	RESULTS OF "C" TEST
	350-μH chokes				
1		80	79 good 1 reject replaced		
2		12		1 failed after moisture resistance. 12 shorted after immersion test.	
3		68			68 good after 2000 hours
4	12 elements from group 3 were subjected to a second immersion test. These 12 were encapsulated well. Original 12 were questionable.	12		12 good	
	38-μH chokes				
5		80	80 good		
6		12		2 failed after moisture resistance but recovered in 2 weeks. 12 shorted after immersion test.	
7		68			68 good after 2000 hours
8	12 elements from group 7 were subjected to a second immersion test. These 12 were encapsulated well. Original 12 were questionable.	12		1 shorted. 3 failed insulation-resistance check after immersion. 8 good.	

TABLE 3.3.5-1 Results of Inductor Acceptance-Test Program

TEST STAGE	RESULTS OF CHECK FOR										
	VISUAL AND MECHANICAL	INSULATION RESISTANCE	DIELECTRIC STRENGTH	TEMPERATURE COEFFICIENT	OVERLOAD	HIGH TEMPERATURE	D-C RESISTANCE	(c) →	INDUCTANCE (μH)	Q	SELF RESONANT FREQUENCY (mc)
350-μH CHOKES											
After winding and impregnation	ok	-	-	ok (b) average +328 ppm/°C	-	-	-	min. max.	328 375	50.5 60.2	8.8 13.0
After mounting and final impregnation	ok	ok	ok	-	-	-	-	min. max. average change	340 380 +1.4%	49 59.8 -2%	- - - -
After assembly into module	ok	ok	ok	-	-	-	-	min. max. average change	335 385 +0.85%	49 61 +1.5%	- -- -
After encapsulation	ok	ok	ok	-	ok (d)	ok	ok	min. max. average change	350 385 +1.6%	49 58 -2.2%	4.7 6.2 -48%

TABLE 3.3.5-2 Summary of Acceptance "A" Tests for Inductors (Sheet 1 of 2)

TEST STAGE	VISUAL AND MECHANICAL	INSULATION RESISTANCE	DIELECTRIC STRENGTH	TEMPERATURE COEFFICIENT	OVERLOAD	HIGH TEMPERATURE	D-C RESISTANCE	(c)→	INDUCTANCE (μH)	Q	SELF RESONANT FREQUENCY (mc)
	RESULTS OF CHECK FOR										
38-μH CHOKES											
After winding and impregnation	ok	-	-	-	-	-	-	min.	34.9	105	29
								max.	38.9	117	36
After mounting and final impregnation	ok	ok	ok	-	-	-	-	min.	35.5	104	-
								max.	39.5	116	-
								average change	+2.6%	-1.85%	-
After assembly into module	ok	ok	ok	-	-	-	-	min.	34.9	105	-
								max.	40.0	118	-
								average change	-0.3%	+1.6%	-
After encapsulation	ok	ok	ok	ok (b) average -34 ppm/°C	ok	ok	ok	min.	35.1	102	16.8
								max.	40.2	114	20.8
								average change	+0.8%	-4.6%	-43%

Notes:
a. Dash indicates that test is not applicable or no test was performed.
b. Temperature coefficient measured with a test winding on a sample basis.
c. Average change calculated from individual samples.
d. One element was open after encapsulation. This element failed during encapsulation.

TABLE 3.3.5-2 Summary of Acceptance "A" Tests for Inductors (Sheet 2 of 2)

TEST STAGE	RESULTS OF CHECK FOR									
	VISUAL AND MECHANICAL	INSULATION RESISTANCE (megohms min.)	DIELECTRIC STRENGTH (at 100vdc)	INDUCTANCE AVERAGE	INDUCTANCE MAXIMUM	Q (QUALITY FACTOR) AVERAGE	Q (QUALITY FACTOR) MAXIMUM	SELF RESONANT FREQUENCY AVERAGE	SELF RESONANT FREQUENCY MAXIMUM	TEST STATUS
350-μH CHOKES										
After encapsulation	ok	30×10^6	ok	364 μH	-	54.5	-	6.65 mc	-	ok
After high temperature (125°C for 24 hours)	ok	28×10^6	ok	-1.5%	-3%	-0.23%	-4.0%	+2.2%	+6%	ok
After vibration	ok	30×10^6	ok	-0.5%	-2.2%	+0.3%	+3.4%	+0.5%	+1.8%	ok
After shock	ok	29×10^6	ok	-0.2%	-0.57%	+2.4%	+3.5%	+0.2%	+0.74%	ok
After moisture resistance	ok	30×10^3	ok	-1.0% -	-3.3% -21%(b)	-4.3% - -	-5.0% +9% -11%(c)	+0.4% -	+1.3% +4.6%	ok failed
After immersion	ok	failed	failed	11 failed		12 failed		11 failed		failed
"C"-test coils after immersion	ok	22×10^6	ok	-0.2%	-0.79%	+0.45%	+1.6%	-0.75%	-3.1%	ok

TABLE 3.3.5-3 Summary of Acceptance "B" Tests for Inductors (Sheet 1 of 2)

TEST STAGE	RESULTS OF CHECK FOR									
	VISUAL AND MECHANICAL	INSULATION RESISTANCE (megohms min.)	DIELECTRIC STRENGTH (at 100vdc)	INDUCTANCE AVERAGE	INDUCTANCE MAXIMUM	Q (QUALITY FACTOR) AVERAGE	Q (QUALITY FACTOR) MAXIMUM	SELF RESONANT FREQUENCY AVERAGE	SELF RESONANT FREQUENCY MAXIMUM	TEST STATUS
38-μH CHOKES										
After encapsulation	ok	28 x 10^6	ok	33.2 μH	-	109	-	24.3 mc	-	ok
After high temperature (125°C for 24 hours)	ok	28 x 10^6	ok	+7.5%	+11%	+2.3%	+4.6%	-5%	-6.5%	ok
After vibration	ok	28 x 10^6	ok	+0.46%	+1.6%	-1.1%	-5.3%	-0.83%	-4.2%	ok
After shock	ok	28 x 10^6	ok	+0.07%	+0.3%	+1.7%	+6.6%	+1.1%	+6.4%	ok
After moisture resistance	ok	750	ok	+2.1%	+3.3%	-2.6%	-3.9%	-1.3%	-4.4%	(d)
After immersion	ok	failed	failed	No readings on 3		failed		-4.7%	-12.5%	failed
"C"-test coils after immersion	ok	4 failed	1 shorted	+0.1%	+0.6%	-3.6%	-49%	-3.4%	-9%	failed

Notes:
a. Average change calculated from result of previous check on individual samples.
b. One failed.
c. One lost 11% in Q after moisture-resistance test but recovered after 2 weeks.
d. Two failed for low insulation resistance but recovered after 2 weeks.

TABLE 3.3.5-3 Summary of Acceptance "B" Tests for Inductors (Sheet 2 of 2)

TEST STAGE	RESULTS OF CHECK FOR								
	VISUAL AND MECHANICAL	INSULATION RESISTANCE (megohms x 10^6 min.)	DIELECTRIC STRENGTH (at 100vdc)	INDUCTANCE AVERAGE	INDUCTANCE MAXIMUM	Q (QUALITY FACTOR) AVERAGE	Q (QUALITY FACTOR) MAXIMUM	SELF RESONANT FREQUENCY (mc average)	TEST STATUS
56 350-μH CHOKES									
Initial readings	ok	30	ok	369 μH	-	53.8	-	5.6	ok
After 500 hours (at 85°C and 3 ma dc)	ok	27	ok	+1.2%	+2.5%	-2.3%	-4.7%	-	ok
After 2000 hours	ok	45	ok	+1.0%	+2.5%	-1.7%	-3.8%	-	ok
12 350-μH CHOKES									
Initial readings	ok	36	ok	373 μH	-	53.7	-	6.6	ok
After 500 hours (at 85°C and 3 ma dc)	ok	30	ok	+2.1%	+4%	-4.8%	-6.6%	-	ok
After 2000 hours	ok	50	ok	+2.2%	+4.1%	-5.1%	-6.2%	-	ok
68 38-μH CHOKES									
Initial readings	ok	0.16	ok	33.1 μH	-	106	-	18.6	ok
After 500 hours (at 85°C and 10 ma dc)	ok	10	ok	+0.75%	+1.9%	+1.6%	±5%	-	ok
After 2000 hours	ok	40	ok	+1.3%	+3%	+1.9%	+4.9%	-	ok

Notes: a. Average change is calculated from initial values on individual samples.
b. Dash indicates that test is not applicable or no test was performed.

TABLE 3.3.5-4 Summary of Acceptance "C" Tests for Inductors

ELEMENT TYPE	THICKNESS (inches)		INDUCTANCE		QUALITY FACTOR		SELF RESONANT FREQUENCY		TEST FREQUENCY (kc)
	MAXIMUM	MINIMUM	MEAN (µH)	MAXIMUM DEVIATION (%)	MEAN	MAXIMUM DEVIATION (%)	MEAN (mc)	DEVIATION (%)	
1500 µH choke	0.0815	0.0965	1436	±5	53	±10	4.70	±13	250
600 µH choke	0.081	0.086	601	±4	70	±3	3.53	±9	790
350 µH choke	0.067	0.075	378	±7	-	-	10.7	±17	1
2.4 µH choke	0.067	0.072	2.44	±8	55	±7	163	±8	7900
38 µH choke	0.074	0.083	38.4	±6	-	-	39.6	±7	1

Note: Dash indicates that test is not applicable or no test was performed.

TABLE 3.3.6-1 Summary of Tests of Final-Grade Chokes for Delivery to the Signal Corps

ELEMENT TYPE	PRIMARY INDUCTANCE MEAN (µH)	PRIMARY INDUCTANCE MAX. DEVI-ATION (%)	PRIMARY Q MEAN	PRIMARY Q MAX. DEVI-ATION (%)	PRIMARY TAP INDUCTANCE MEAN (µH)	PRIMARY TAP INDUCTANCE MAX. DEVI-ATION (%)	PRIMARY TAP Q MEAN	PRIMARY TAP Q MAX. DEVI-ATION (%)	6-DB BAND WIDTH MEAN (kc)	6-DB BAND WIDTH MAX. DEVI-ATION (%)	LOSS MEAN (db)	LOSS MAX. DEVI-ATION (%)	INPUT IMPEDANCE MEAN (kil-ohms)	INPUT IMPEDANCE MAX. DEVI-ATION (%)	VOLTAGE RATIO MEAN (v)	VOLTAGE RATIO MAX. DEVI-ATION (%)
4.3-mc i-f transformer	7.73	±6	58	±9	-	-	-	-	202	±2	7.48	±6	2.35	±7	3.92	±9
4.3-mc i-f transformer	7.76	±5	57	±5	-	-	-	-	287	±3	4.34	±6	1.57	±7	2.07	±4
4.3-mc dis-criminator secondary transformer	7.99	±5	58	±4	3.13	±3	50	±3	-	-	-	-	-	-	-	-
50-mc r-f transformer	0.74	±5	82	±3	0.085	±4	65	±7	8550	±9	-	-	0.087	±18	1.47	±9
50-mc r-f mixer transformer	0.67	±9	78	±4	-	-	-	-	3092	±14	1.05	±14	2.16	±22	-	-
45-mc oscil-ator trans-former	0.373	±6	77	±4	-	-	-	-	-	-	-	-	-	-	-	-

Notes: a. Dash indicates that test is not applicable or no test was performed.
b. Voltage ratio was measured at resonance and under loaded conditions. Measurement was made between primary tap and secondary.
c. 15 units of each type were tested.

TABLE 3.3.6-2 Summary of Tests of Final-Grade R-F and I-F Transformers for Delivery to the Signal Corps

ELEMENT TYPE	INDUCTANCE (at 790 kc)		QUALITY FACTOR (at 790 kc)		COUPLING FACTOR				DYNAMIC PERFORMANCE							
					K		K RATIO		OUTPUT		RISE TIME		PULSE WIDTH		OVERSHOOT	
	MEAN (μH)	MAX. DEVIATION (%)	MEAN	MAX. DEVIATION (%)	MEAN	MAX. DEVIATION (%)	MEAN	MAX. DEVIATION (%)	MEAN (v p-to-p)	MAX. DEVIATION (%)	MEAN (μ-sec)	MAX. DEVIATION (%)	MEAN (μ-sec)	MAX. DEVIATION (%)	MEAN (v p-to-p	MAX. DEVIATION (%)
750-pps pulse transformer	208	±12	45	±9	0.918	±2	0.969	±3	8.7	±2	0.165	±13	1.34	±15	0.99	±6

Note: All dynamic tests were made in the circuit of the XM-28B Micro-Module.

TABLE 3.3.6-3 Summary of Tests of Final-Grade Pulse Transformers for Delivery to the Signal Corps

3.3.7 TEST EQUIPMENT FOR "A", "B", AND "C" TESTS

3.3.7.1 "A" TEST EQUIPMENT

The commercial test equipment used for "A" tests is listed in the following table.

Name	Model No.	Manufacturer	Used in
Q Meter	260A	Boonton Radio	Inductance, Q, and input-impedance measurements
RX Meter	250A	Boonton Radio	Bandwidth and insertion-loss measurements
Electronic Counter	524B	Hewlett-Packard	Resonant-frequency and bandwidth measurements
Megacycle Meter	59	Measurements	Self-resonant frequency measurements
Crystal Calibrator	111B	Measurements	Frequency calibration
Pulse Generator	212A	Hewlett-Packard	Pulse-transformer measurements
Oscilloscope	535	Tektronix	Pulse-transformer measurements
RF Signal Generator	606A	Hewlett-Packard	Voltage ratio measurements
RF Voltmeter	91C	Boonton Radio	R-f voltage measurements
RF Voltmeter	314	Balantine	R-f voltage measurements
Demagnetizer	202	Kendric and Davis	Demagnetizing pulse transformers
Inductance Bridge		Leeds and Northrup	Inductance measurement at 1 kc
Binocular Microscope		Bausch and Lomb	Mechanical inspection
Megatrometer	710	Mid-Eastern Electronics	Insulation-resistance and dielectric-strength measurements

TABLE 3.3.7-1 Commercial Test Equipment used in "A" Tests

3.3.7.2 "B" AND "C" TEST EQUIPMENT

Vibration Equipment

The Model T 151 electronic amplifier, used for vibration tests, consists basically of a type T 104-A automatic vibration exciter control, a power amplifier, and a d-c field supply. The T 104-A equipment and power amplifier provide variable-frequency power to a vibration-exciter driver coil. The automatic vibration exciter control consists of an oscillator, a frequency-sweep unit, a vibration meter, an automatic level control, and an automatic displacement-acceleration transfer unit. This exciter control drives an MB Model C10 Vibration Exciter which is a high-force high-frequency electro-dynamic vibration exciter. Forced-air cooling allows continuous operation at rated force.

Vibration Test Fixture

This fixture is 4 by 4 by 3.5 inches and is made of steel. On top of the fixture are two 0.750-diameter 1.00-inch-deep holes. The fixture also has the same size hole on each of the four sides. The module is mounted on a printed-circuit board which is held in place on the test fixture by two 8-32 screws. A total of six modules can be vibrated at one time.

Shock Equipment

The main structure of the shock-testing apparatus (MIL-STD-202A, Figure 202-1) consists of a cast-iron base to which upright channels are securely bolted. The tops of the upright channels are secured to a top channel which also supports rods to guide the movable carriage assembly. The bottom ends of the guide rods are screwed into the base. The carriage assembly carries, on its under side, a stiff calibrated spring resiliently mounted. A cylindrical bearing is mounted on the base where the spring makes contact when the carriage is dropped.

Immersion Equipment

A Model 9923-1 stainless steel open bath is heated by a sheathed circular strip heater. The temperature is controlled by a totally-enclosed thermoregulator, and three input steps are provided by a three-way switch.

The following approximate maximum controlled temperatures are available:

SWITCH POSITION	TEMPERATURE (^{o}C) UNCOVERED BATH	COVERED BATH
Low	45	80
Medium	60	100
High	75	100

Moisture Resistance Equipment

A Tenney TH16 temperature humidity chamber and a Bristols T 500 Temperature Controller were used in the moisture resistance tests.

Group C Test Equipment

An American Instrument Co. No. 4-3522 Forced Draft Oven, designed to operate on 230-watts of 60-cps, single-phase power was used for "C" tests. The maximum operating temperature of this oven is 250°C.

3.4 PRODUCT COMPARISON

3.4.1 ENGINEERING

The toroidal-coil design used in the Micro-Module can be compared to conventional coils of the pot-core, cup-core, or slug types. The toroidal construction, because of its flat shape, is most easily adapted to the Micro-Module. Pot cores permit a minimum volume; however, the geometry of these cores precludes a flat package. Cup-core and slug-core configurations are much larger than the toroidal or pot-core types because they do not provide continuous magnetic paths.

Self-shielding and stray-field effects are of paramount importance in the module due to the intimate spacing of the components and circuitry. The toroidal construction offers the highest degree of shielding of any configuration considered. Further, since the entire length of the core can be used as the winding length, stray fields are minimized. Pot-core construction comes the closest to equaling toroidal core performance since the core entirely surrounds the winding except for lead entries and the gap between the cores themselves. The latter gap can be minimized by grinding the surface of the cores. Cup cores or slug-type core have the inherent disadvantage that the magnetic circuit is not continuous, thus permitting a high degree of stray field and lack of shielding.

The inductance range attainable is limited by the effective permeability of the core material and the configuration. Toroidal and pot-core constructions excel in this parameter. Pot-core constructions can develop higher Q's since the magnetic construction can be gapped internally to match copper and core losses. The Q of the toroidal construction is dependent solely upon the material used. Q's of toroidal cores have been optimized by introducing non-magnetic materials in the core mix, such as carbon in the case of ferrites and resin in the case of powdered-iron cores, to effectively produce a distributed gap which can be designed to equalize the losses and maximize Q.

Over-all coil stability is dependent on the temperature characteristics of the magnetic material as well as the mechanical design of the core and coil. In the pot-core construction an air gap can be deliberately introduced, as indicated above, to limit the effect of material variation with temperature.

A small air gap will virtually eliminate core-material variations. The control of this mechanical gap, however, can easily introduce undesired temperature effects, thus, a compensating type design is required to achieve a high degree of stability. In the case of toroidal coils, stability is almost entirely dependent on the inherent properties of the magnetic materials.

Flexibility in design is almost equal between toroidal and pot-core constructions, with pot cores having a slight advantage due to the possibility of adjusting the air gap to adjust final inductance. The toroidal coil can be adjusted only by changing the number of turns or the spacing between turns or windings.

In summary, the selection of the toroidal coil configuration was a compromise in which performance requirements of self-shielding, flat geometry, mechanical stability, and low distributed capacitance were obtained at the expense of higher cost, less convenient adjustment procedures and a little less flexibility.

3.4.2 COST

The cost of the toroidal construction is inherently higher than that of pot-core, cup-core or slug constructions. This is primarily due to the inherent difficulty of winding toroidal coils. Toroids must be wound one at a time while conventional coils can be wound in multiple. Inductance adjustment of the conventional types is also a simpler operation because of the adjustable gap feature. The adjustment of toroidal types involves adding or removing turns or adjusting the spacing of the turns.

Toroidal windings for R-f and I-F applications of the type used in this program would cost twice to two and one half times the cost of conventional windings, depending on the complexity and quantity to be produced. While no firm basis is available at the present time for a comparison, it is estimated that chokes would cost about $2.00 each compared with a conventional choke cost of $0.50. Transformers (I-F and R-F) cost an estimated $3.00 each while conventional transformers cost $1.50. At present, the predominant cost is that of the core itself and occurs as a result of the strict stability requirements. Increased experience, resulting in improved yields, can be expected to substantially reduce the cost of cores and thus the cost of coils. Table 3.4.2-1 indicates the labor time allowance achieved during the initial program.

3.4.3 PRODUCTION

Factors affecting the production of microelement coils have been discussed in the above two paragraphs. Since toroidal coils must be wound one at a time, it is essential that semiautomatic winding equipment be developed permitting the operation of several machines by one operator. Improved precision in placing the turns on the core is expected to reduce the need for postadjustment of the toroidal coils. Introduction of core-grading techniques can also lead to more uniform output and reduction in final adjustment. Testing techniques will be substantially the same as for conventional coils and tests may be made of static parameters or dynamic characteristics.

ITEM	TIME IN MINUTES		
	ISOLATION CHOKE (2 leads)	I-F TRANSFORMER (6 leads)	R-F TRANSFORMER (5 leads)
Treat or test and treat core	0.36	0.86	0.86
Wind or wind and code	1.96	5.47	10.27
Treat and assemble to substrate	1.83	3.24	2.84
Test and inspeet or test and adjust	1.00	10.00	15.00
Total time	5.15	19.57	28.97
Correeted load-labor allowanee	6.07	23.00	33.10

TABLE 3.4.2-1 Labor-Load Allowances for Producing Various Inductor Types

3.5 COMPLETE PROCESS SPECIFICATION

3.5.1 DESCRIPTION OF FABRICATION PROCESS

The complete process for producing inductor microelements is shown in Figure 3.5-1. Major steps are as follows:

1. Cores from all shipments were inspected and tested to a RCA purchase drawing when received. The same statistical quality control was used as on other components.

2. Cores with more closely controlled permeability requirements than the standards to which the cores were purchased, were then selected and re-identified.

3. Carbonyl iron cores were coated with Pliolite per MS-2025878, Part A.

4. Coils requiring sizes 44 to 38 wire were wound on the modified Boesch "Minitor" toroid winder Formvar or Nyleze magnet wire. Coils requiring sizes 34 or 32 wire were hand wound. All transformers were color-coded during the winding process within a half inch of the core.

5. After winding, all cores and coils were inspected to the winding specification. On new setups, L and Q were spot tested at this time.

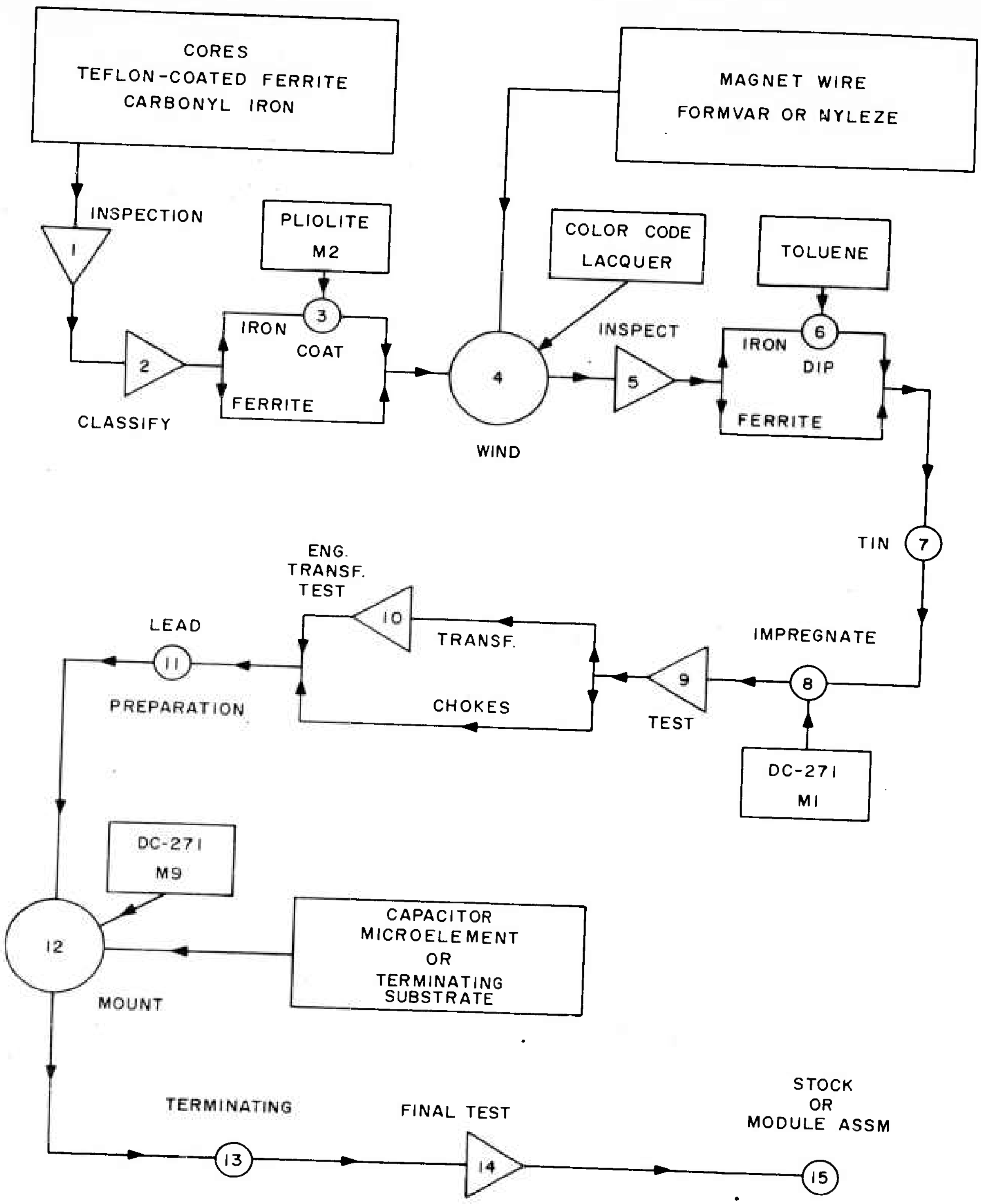

FIGURE 3.5-1 Process Flow Chart for Inductors

6. Cores and coils on powdered iron cores (previously coated with Pliolite) were dipped in Toluene per MS-2025878, Part B to adhere the touching turns firmly to the core.

7. All cores and coils had their leads tinned to within a half inch of the core as described in the detailed process. This was necessary for in-process testing.

8. All cores and coils were impregnated with DC-271 per MS-202587, Part C.

9. Inductance and Q of all choke and transformer primaries were checked on a Boonton Model 260A "Q" meter to limits contained on the winding specification. A serial identity was given each program inductor at this point.

10. Core and coils of transformers only were sent to Test Engineering where the coupling parameters were tested.

11. Leads were dressed and the final tinning accomplished as described in the process detail.

12. The unit was mounted on the terminating substrate (capacitor for resonant elements) using DC-271 as per MS-2025878, Part E.

13. The leads were dressed under a magnifier, placed on the soldering (holding) fixture and soldered.

14. All final units were performance-tested and safety-tested (dielectric and leakage resistance tested).

15. Completed and approved units moved to micromodule assembly or were placed in short time stock.

3.5.2 PREPARATION OF INDUCTOR COMPONENTS

3.5.2.1 FERRITE-CORE PRODUCTION

<u>Flow Diagram</u>

The process by which ferrite cores are constructed is shown in block-diagram form in Figure 3.5-2.

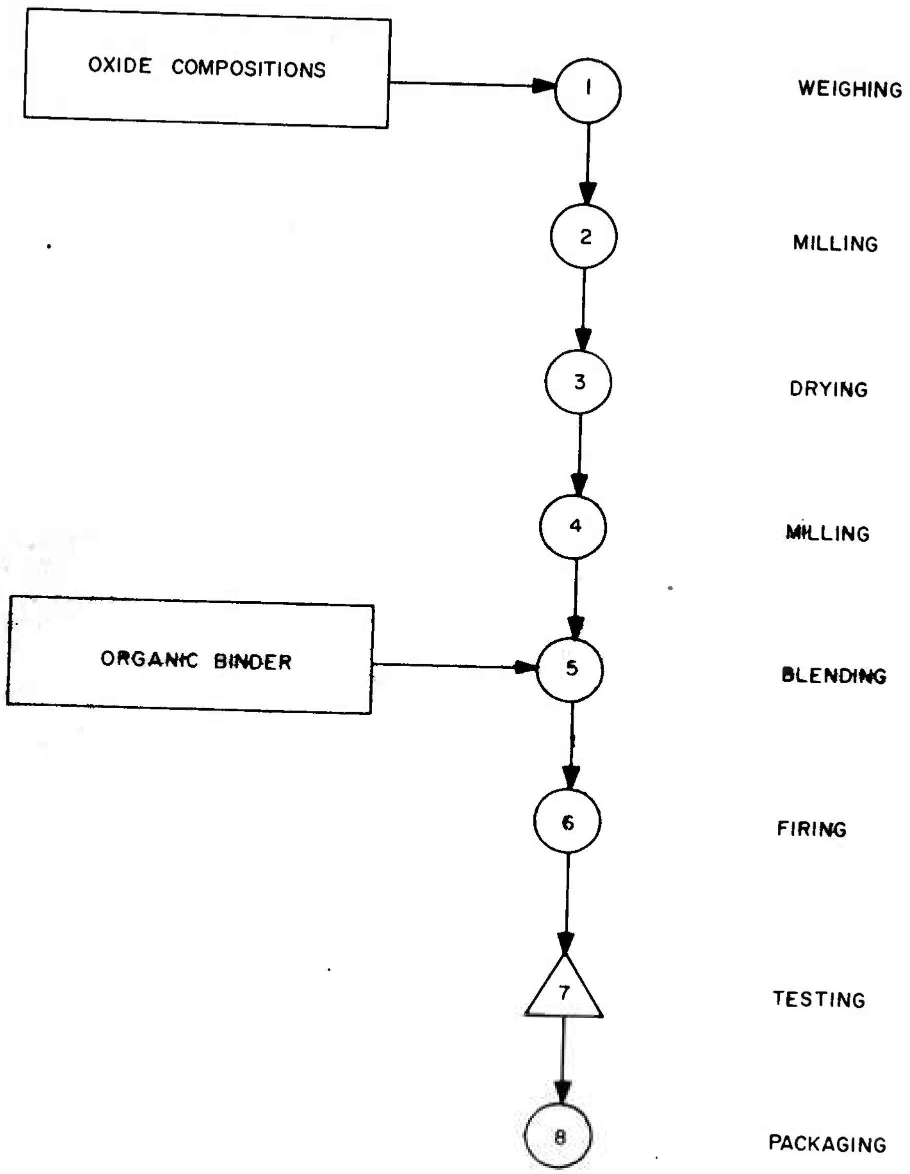

FIGURE 3.5-2 Process Flow Chart for Ferrite Cores

3.5.2.2 DESCRIPTION OF PROCESS

1. Weighing -- The ferritc cores are of four different compositions, as follows:

   XF-3732 - $Fe_2 0_3$, NiO, ZnO, NoO_3, Co_2O_3

   XF-3909 - $Fe_2 0_3$, NiO, ZnO, BaO_2

   XF-3983 - $Fe_2 0_3$, NiO, ZnO, MoO_3, Co_2O_3, Carbolac

   XF-3980 - $Fc_2 0_3$, NiO, ZnO, MoO_3, Co_2O_3

   The oxides are wcighed on an analytical balance to establish proper ratios of ingrcdients.

2. Milling -- The combined ingredients are wet milled for one hour in a Szegvari Attritor, Size -01, charged with No. 003 steel sphercsfor small batches. Heavier batches are milled in a Szegvari Attritor, Size -1S, charged with 1/4 inch diameter steel spheres.

3. Drying -- The slurry is then poured in glass trays and dried in a circulating oven to bone dryness.

4. Milling -- The dried mixture is pulverized in Mikro-Samplmill, rotating at 8000 rpm in order to break up agglomerates.

5. Blending -- An organic binder dissolved in the proper medium is added to the processed oxides. The slurry is agitated in a Hobart Mixer for 45 minutes to insure thorough blending. The semisolid blend is passed through a rubber mill which has extra-hard steel rolls to form laminates and to eliminate some of the solvent. The remaining solvent is driven off either by vacuum methods or by aeration. The laminates are subsequently sifted on a Ro-Tap sifter or similar device. When the powder has been recovered, it is ready for pressing. Samples of the powder are pressed into toroids by means of a Model F-4 Stokes dual-pressure press. These samples are fired and tested as described below. If they meet specifications, the remainder of the batch is processed as described in steps 6 and 7. During pressing, the cores are continually examined with a microscope for defects, and checked for dimensions.

6. Firing -- The pressed toroids are then sintered in a muffle furnace at a specific rate of temperature rise for a predetermined rate of time at peak temperature.

7. Testing -- Ten per cent of the cores from each batch are wound with copper wire and tested for permeability and Q. Temperature coefficient is also determined.

8. Satisfactory units are packaged and stored for future assembly into inductor microelements.

3.5.3 WINDING OF COILS

Inductors were wound both by hand and by machine. Inductors for vhf use were wound by hand with heavy magnet wire. Other inductors were wound on the modified Boesch Minitor toroid winding machine. In both cases, winding instructions were issued in the form of a core and coil standard which specified the required core, the magnet wire size, the winding pitch, the number of turns to tap and finish of both coils and the location of the secondary start relative to the primary. As a check on the winding pitch, and for inspection purposes, the angles of the finishes were also specified.

3.5.3.1 HAND WINDING

Fortunately, the designs required less than 25 turns on any one coil of AWG 32 or 34 magnet wire, which made hand winding a simple but tedious process. The primary winding was wound first by threading an approximate precut length of heavy Formvar wire through the core, and controlling the pitch by visual comparison with a sample until the required number of turns to the tap were applied. A foot-treadle-actuated counter was used to maintain the count as the turns were applied with the operator using both hands and working through a magnifying glass. At the tap, a 1-inch length was doubled and held in position under the thumb while the remaining turns were applied to complete the coil. The pitch had to be uniform and the finish lead had to lie within the specified angle. The tap was twisted tightly to anchor it close to the core surface, and the three leads were color-coded with lacquer to within a half inch of the core. The secondary was applied next, starting at a definite location referred to the primary and interwinding it into the primary. The secondary was then color-coded. An enlarged sketch, appearing in the microelement specification, was used for added detail of dress in the vicinity of the taps. The finished windings were inspected against this sketch and also compared to a winding standard under 10-power magnification. (Acceptable coils have the Formvar insulation removed from their leads to within a half inch of the core with Formvar stripper Super X.) The leads were then tinned and washed.

3.5.3.2 MACHINE WINDING SHUTTLE-LOADING PROCESS

All chokes and transformers wound on the modified Boesch Minitor were wound from shuttles loaded in a setup consisting of an 0.015-inch diameter mandrel and pusher and the necessary cutting and dressing tool inserts. Thus, in setting up the loader for any inductor type, only the wire size and tension had to be changed. With wire from the same spool spiralled from the same mandrel, abuse to the magnet wire could be caused only by excessive tension. For this reason, whenever a different size wire was to be loaded, the tension was adjusted to a prescribed value as measured on a postal scale.

In loading a shuttle, wire from the mandrel was spiralled through the empty shuttle holder block and the loader was stopped. The spiral was then stretched just enough to separate its turns slightly and the holding lever was lowered to grip the spiral firmly in the block. Next, the wire in the external spiral was pulled taut and removed with the cut-off lever. At this point, the automatic stop was reset, the

shuttle was inserted into place, and the loader switch was turned on. The loader now filled the shuttle, threaded the nozzle and stopped automatically, permitting the operator to be winding while the shuttle was loading. When the operator was ready to use the shuttle, the spiral was cut off with the cut-off lever, the shuttle was removed from the loader, and the end of this wire was pulled through the nozzle far enough to cause the excess spiral to completely enter the shuttle. The shuttle was then ready for winding.

3.5.3.3 MACHINE WINDING, WINDING PROCESS

All chokes and transformers were wound from 0.050-inch diameter shuttles so that the machine did not have to be set up to drive different sizes of shuttles. The nozzle holes were 0.008 inch for AWG 38 and 40 wire and 0.006 inch for AWG 42 and 44. All nozzles were adequately stoned and checked for wire abuse.

In winding a choke or transformer the operator set the winding pitch, placed the specified core in the core-vise and threaded the open end of the shuttle through the core from above. Rotating the shuttle until the nozzle was on top, the operator joined the ends at the nozzle, being careful not to pinch the wire. With the nozzle held closed, the shuttle was positioned in the three fixed drive pulleys and the keeper-pulley was lowered locking the shuttle into place. The centering of the shuttle in the core was then checked and adjusted, if necessary. Next the shuttle was turned by hand until the nozzle was just below the core. The core was rotated by hand into the start position (usually zero index on the turret). With the turns counter set for the required number of turns, the brush and counter arm were moved into operating position with the counter set.

With the start lead held taut, the machine was started and operated at a shuttle speed of approximately 200 rpm. After the required number of turns had been applied, the machine stopped. If the coil was a two-lead choke, the winding was complete at this point and the coil was removed from the shuttle by cutting the finish lead, raising the lock pulley, opening the shuttle, and lifting off the core and coil. The next core was then placed in the core vise and the same shuttle was returned to the machine. The winding operation was repeated until the wire remaining in the shuttle was not sufficient for another coil. At this point, the remaining wire was pulled from the shuttle. A full shuttle was taken from the loader and the empty one inserted in the loader in its place to be loaded while the operator was winding the next coil.

Transformers with many leads and accurately located secondaries require a somewhat more involved winding process. Up to the point where the machine stopped for the first time, a primary transformer tap for instance, the process was exactly the same as for a choke. For the transformer, however, a tap was made at this point by pulling excess wire from the shuttle, resetting the counter, holding the tap wire, and starting the machine again.

To accurately locate the tap, the wire was held in the shuttle plane while the machine started and, at the next stop, the wire was twisted tightly up to the core. At this point, the start and tap were color-coded with lacquer about half an inch from the core. Additional taps were brought out by the same method and the winding was

finished. The wires were then cut and color-coded. To apply the secondary winding the turret was reversed by hand to the angle specified for the secondary start. While the turret was being severed, the finish lead and any others that passed the shuttle plane were pulled past the counter plate. If the secondary had to be wound past one or more taps, the machine had to be stopped at the angle (or number of turns) of each tap position and the tap had to be moved through the shuttle plane by hand, otherwise the tap would be wound into the secondary winding. Taps were brought out, leads were coded, and the coil was removed from the shuttle as previously described.

3.5.3.4 FIXING OF WINDINGS

Windings applied to Pliolite coated cores were dipped in toluene for two seconds to anchor the turns to the core. The coils were then air-dried for fifteen minutes and cured for thirty minutes at 100°C.

In this operation, the softened Pliolite flowed between the wire and core at the corners, and when the coil was cured the Pliolite held the first-layer turns in place. Machine-wound coils are inspected against the winding specification for wire type and size, coding and relative location of coils and leads, build and pitch uniformity, and absence of loose turns. Leads are cut to a length of approximately one inch, stripped, and tinned to within half an inch of the coil.

3.5.4 PREPARATION OF COIL LEADS

The extremely short, precise lead lengths required from coil to notch and the delicate nature of fine magnet wire resulted in two strip and tin operations on all inductors. After the winding operation, all leads are precut to approximately 1- or 2-inch lengths and tinned, usually by dip methods to within approximately one half inch of the core body. This procedure prepares the core and coil for testing. Lead preparation is a precise, tedious operation since magnet wire insulation must be retained at any point where the lead crosses another terminal or other leads. The process varies with the magnet wire. Formvar was used exclusively on hand-wound coils while Nylese was used on machine-wound coils.

Both processes involve visual centering of the core and coil on a dummy substrate and predressing the leads under a magnifier. While dressed precisely in accordance with the manufacturing specification, each lead is pushed into its terminal notch. The wire is marked with a bend or kink at the notch edge. The coil is then removed with a demagnetized tweezer and the leads are dipped accurately to this bend. Formvar wire is dipped in Super X stripper, wiped with porous paper, dipped in low-temperature solder (60-37-3 at 240°C) and washed. When coils are wound with Nylese wire, each lead is dipped in flux and in high-temperature solder (60-37-3 + cu at 360°C). The coil is protected from sputter by an aluminum handling shield. The lead is pushed into a narrow slot at the marked length and dipped to the surface of the hot solder. Precise stripping is accomplished by both methods.

3.5.5 COIL IMPREGNATION

The impregnation process varied with the type of inductor. The impregnant, being difficult to remove and detrimental to lead preparation, was kept off the leads as much as possible. This meant that dipping was satisfactory only for coil assemblies where leads emerged from the same area. All chokes were of this type, but transformers, having leads in all quadrants, had to be handled differently. Units with Teflon-coated ferrite cores and those with Pliolite coated powdered-iron cores were impregnated by the same process after the Pliolite-coated units had been dipped in a solvent to anchor the turns touching the core.

The impregnant, DC-271-M1, was made by diluting 100 grams of Dow Corning DC-371 with 120 cubic centimeters of stock solvent consisting of 60 per cent xylol and 40 per cent MEK. The viscosity was checked weekly and maintained such as to empty a No. 3 Zahn cupful of the impregnant through the orifice provided in an elapsed time of from 17 to 22 seconds.

The coil was held by the leads and submerging just below the surface of the impregnant for 10 to 15 seconds, then slowly withdrawn and drained over the impregnant for one to two minutes. The coil was then air-dried (with adequate ventilation) for 15 minutes to remove the solvent and cured for one hour in a 135°C circulating oven.

Transformers with leads preventing a dipping operation were held above a container and two or three drops of impregnant were dropped over the toroid body and through the hole. The unit was then turned over and the operation was repeated on the other side. The unit was drained in the level position and air-dried and cured as described above. Alligator clips with teeth removed were used to handle the coil assemblies in batches during these operations.

3.5.6 MOUNTING AND TERMINATING OF INDUCTOR

The material used to affix the core and coil to the substrate (M9 in manufacturing specifications) is 90% by weight Dow Corning DC-271 and 10% MEK. The viscosity is checked weekly and controlled to 3400 $\pm$ 500 Centapoise at 25°C ($\pm$ 3°) on a Model RVF Brookfield Viscosimeter using a No. 4 spindle at 10 rpm. The process follows. The substrate on which the core and coil is to be mounted is placed under a magnifier right side up and rotated as shown on the microelement manufacturing drawing. Using a toothpick, a drop of M9 is carefully placed in the center of the substrate. The size of the drop should be controlled so that when it spreads, it covers the area on which the coil rests but does not foul the notch terminations. After the M9 has spread it is set aside for 8 or 10 minutes until the surface gells and it does not flow readily. At this time, the core and coil (with already prepared leads) is centered above the substrate, rotated into position and lowered into the drop of M9. Care must be exercised throughout the terminating which follows to avoid moving the coil and pushing the M9 onto the metalization.

With the core and coil adherred in position, the leads are carefully dressed into their proper notches. The stripped portion of the magnet wire must be kept over the metalization so that no bare wire exists at crossovers. A sharp bend is made in each lead

at the noteh edge so that the lead can quiekly be relocated in the soldering operation. The assembly is now earefully transferred to a soldering jig eonsisting of a small Teflon block which nests the substrate and a sprung leather-tipped plunger whieh holds the coil eentered against the substrate. The Teflon bloek holds the substrate at the corners leaving the notehes open for the soldering operation. The entire holding seetion ean be swiveled permitting soldering to be done from above. Eaeh lead is held in position with a tweezer and soldered into the bottom of the noteh using flux and a 275°C soldering iron. The excess magnet wire is then cut off and the finished unit plaeed in a 135°C oven for one hour to cure the M9 adherrant. On removal from the oven the units are inspeeted to the final assembly manufacturing drawing and for quality of the solder joints and sent to final microelement test.

3.5.7 TESTING OF INDUCTOR MICROELEMENTS

Table 3.5-1 shows all the tests, exeept environmental and life tests, to which parts and eompleted microelement inductors are subjected. Included are in-process manufaeturing tests and performance tests. The tests indicated under the two headings, "AFTER MOUNTING," are performed on eompleted units. All other tests are performed at various stages during the inductor-production process.

To insure satisfaetory product, certain tests and inspections must be performed at various stages in the production process. These tests are indieated under "SPECIAL TESTS AND INSPECTIONS" and are in addition to the required military tests indicated under "MIL-C-15305A".

3.5.8 IN-PROCESS TEST EQUIPMENT

The equipment for all "A" tests, is utilized during the induetor-assembly proeess. For example, cores are tested prior to being wound, and wound inductors are "A" tested prior to being mounted on a wafer.

All of this test equipment is described under Seetion 3.3.7, "Test Equipment for A, B, and C Tests." Table 3.3.7-1 lists the equipment employed and deseribes the "A" tests for whieh it is used.

Subject	Special Tests & Inspections	MIL-C-15305A (Ref. Para)	Tests Required for Final-Grade Elements: Chokes, Before Mounting	Chokes, After Mounting	Transformers, Before Mounting	Transformers, After Mounting
Mech. Requirements						
Wire	x	---	1%	---	1%	---
Pitch Uniformity		Para. 3.19	All	---	All	---
Loose Turns		Para. 3.19	All	---	All	---
Preliminary Impregnation		Para. 3.19	All	---	All	---
Lead Anchoring		Para. 3.43	All	---	All	---
Lead Preparation	x	---	All	---	All	---
Mounting and Final Impregnation	x	---	---	All	---	All
Overall Thickness	x	---	All	All	All	All
Elect. Requirements						
Insulation Resistance		Para. 3.7				
Wire insulation	x	---	5%	---	5%	---
Between Windings		Para. 4.7.4	---	---	---	All
Between Windings and Wafer Notches		Para. 4.7.4	---	All	---	All
Dielectric Strength						
Between Windings		Para. 4.7.3	---	---	---	All
Between Windings and Wafer Notches		Para. 4.7.3	---	All	---	All
Inductance (Primary only on transformers)		Para. 4.7.2	---	All	All	---
Q (Primary, only on transformers)		Para. 4.7.2	---	All	All	---
DC resistance when required on applicable dwg.		Para. 4.7.2	---	---	---	---
Self-Resonant Frequency		Para. 4.7.2	---	5%	---	---
Transformer Coupling						
Coupling Factor (Pulse units only)		Para. 4.7.2	---	---	---	5%
Voltage Ratio (RF & IF units only)	x	---	---	---	All	---
Capacitance between Windings (Pulse units only)	x	---	---	---	---	5%
Temperature Coefficient (Accep. Test only)	x	---	N=12 C=0 N=24 C=1		N=12 C=0 N=24 C=1	
High-Temperature Storage (Accept. Test only)		Para. 4.7.9	---		---	N=12 C=0 N=24 C=1

TABLE 3.5-1 Summary of Inductor Tests (Sheet 1 of 2)

Subject		Special Tests & Inspections	MIL-C-15305A (Ref. Para)	Tests Required for Final-Grade Elements			
				Chokes		Transformers	
				Before Mounting	After Mounting	Before Mounting	After Mounting
Overload (Acceptance test only)			Para. 4.7.6	---	---	---	---
Distributed Capacitance			---	---	---	---	---
Dynamic Performance							
Tank Resonant Frequency			Para. 4.7.2.4.2	---	---	---	All
Reflected Input Impedances	RF & LF		Para. 4.7.2.4	---	---	---	5%
Bandwidth & Q	Transf.		Para. 4.7.2.6	---	---	---	5%
Insertion Loss	only		Para. 4.7.2.6	---	---	---	5%
Comparison Standards			Para. 4.7.2	---	---	---	---
Pulse Transformer				---	---	---	All

TABLE 3.5-1 Summary of Inductor Tests (Sheet 2 of 2)

4. CONCLUSIONS

4.1 GENERAL

The inductor task under the Initial Program had three basic objectives:

1. To demonstrate the feasibility of manufacturing various miniaturized fixed inductors in the Micromodule-element form factor.

2. To demonstrate microelement inductor reliability.

3. To establish supply sources for both cores and inductors, and to make these elements available for use in the Micro-Module Program.

All three of these basic objectives were achieved.

Feasibility was successfully demonstrated by the production of various cores and inductors having the specified characteristics over the frequency range from 100 kc to 50 mc. A high degree of miniaturization was accomplished, and overall performance of the inductors met the basic requirements of module transistorized circuitry. The inductors were required to cover a wide range of circuit applications and performance capability as indicated below:

455 kc . . . . 0.5 to 1 millihenry

4.3 mc . . . . 5 to 50 microhenries

11.0 mc . . . . 5 to 10 microhenries

60.0 mc . . . . 0.3 to 1.0 microhenry

Reliability tests proved that microelement inductors are capable of a high level of performance. These components proved their capability under test conditions of extreme severity, and demonstrated a high order of reliability in Micromodule circuits operated under load-life test conditions. While these module life tests are not completed, the data compiled thus far are significant, and are sufficient to indicate that performance is well in excess of overall Program goals.

Adequate sources for both cores and inductors were established. The RCA Needham, Mass., Laboratories produced ferrite cores of the required characteristics for applications in all preliminary, prototype and final modules. Powdered-iron cores have been produced under Extension I effort by Radio Cores, Inc. and by the Polymer Corp. for use in critical temperature stability applications of final-grade modules. The inductors were wound on specially developed toroidal winding equipment by RCA, Somerville, N. J. These sources developed a high degree of technology in microelement core and inductor fabrication, and collectively represent an established, reliable supply base for microelement inductors which use toroidal cores.

Major technical objectives for the various transformers and chokes were established at the start of the program. These objectives were selected on the basis of the state of the art at that time, the stringent electrical and environmental requirements of military equipment, and the performance requirements of the Micromodules in which the inductors were to be used.

Because the over-all Program required that a practical feasibility be demonstrated at an early date, the specifications for components, including inductors, had to be realistic and competitive with those of conventional military units. The reliability specifications for microelement inductors, however, were made more severe than those ordinarily applied to conventional military components to insure that the elements complied with the over-all Micromodule reliability requirements. All of these basic technical objectives were either achieved, or an ultimate capability was demonstrated. Inductors suitable for all the specified module applications were produced and successfully demonstrated. The detailed requirements for micro-element inductors were established to meet the needs of module circuit performance. These requirements included an inductance range from 0.1 to 1500 microhenries and quality factors (Q) between 50 and 100. Temperature stability requirements ranging from 300 ± 500 to 25 ± 10 PPM/^oC and drive sensitivity needs of 0.2 per cent were also established and met.

4.2 CORES

Both ferrite and powdered iron cores were used in the program. Ferrite cores with temperature stabilities well beyond the previous state of the art were produced for the program. While these cores were not capable of meeting the extensive requirements of the module I-F stages, they did contribute substantially to size reduction in the less critical applications of module circuitry. The preliminary, prototype and final modules utilized ferrite cores in these applications where the advantage of high permeability for a given size and configuration permitted maximum reduction in size. For the more critical applications such as I-F's where a high degree of temperature stability and low drive sensitivity are required, powdered iron cores were used.

The effort on ferrites produced one of the more significant advances in the state of the art demonstrated in the Micro-Module Program. Ferrites having low temperature coefficients were produced. The technology developed under this study proved to be of great value and will undoubtedly be useful as the scope of the microelement inductor needs expands. One ferrite core which proved useful to the present program was a high permeability general-purpose type for lower-frequency applications.

Ferrite materials suitable for pulse transformer and pulse-circuit inductor needs in digital modules were developed, making it possible to incorporate these inductors as microelements in the modules.

Limited effort was applied to the development of a 455-kc core for communication applications since it was not required for program modules. This requirement was eliminated midway through the program, before significant results could be obtained. Satisfactory methods were developed for measuring core parameters, including some

unusual techniques necessitated by the small size of the parts. Dynamic-temperature-coefficient test equipment suitable for testing small cores was designed, permitting continuous-curve tracing of the effect of temperature on core permeability. The non-linear characteristics of the temperature effects revealed by the test made possible the compensation of other components in the module.

Means were developed for coating the cores to minimize the effects of encapsulant stress. This was particularly necessary for ferrite cores which display magneto-strictive properties. The best results were attained by rounding the corners and coating with a film of Teflon.

4.3 COILS

Coil designs suitable for 4.3-mc I-F and 50-mc r-f module applications were developed. The performance of these coils attained a stability of 25 $\pm$10 PPM/^{o}C at 4.3 MC with powdered-iron cores and a stability of -100 $\pm$50 PPM/^{o}C at 50 MC with ferrite cores.

Inductance and Q requirements were met in the toroidal construction without the use of a mechanical gap. The shielding effect of this configuration was entirely adequate, producing no unusual coupling effects in the module. Some shifting of performance in both inductance and temperature coefficient was attributed to initial and aging effects of the encapsulant.

The acceptance test performed on inductors met the basic requirements. The only degradation occurred in moisture-resistance tests, and the degradation here was more a function of the encapsulant and terminations than of the core or coil.

Winding techniques were developed which were basically adequate for the program. Subminiature toroidal winders were adapted to permit machine winding of the finer wire coils. R-F coils, having wire sizes in the order of AWG 32, were hand wound because of the small number of turns involved. The mounting technique for placing the coil on the wafer is an assembly operation which will require some improvement for larger-scale production. Testing techniques are based on the use of laboratory equipment. Measurements have been basically parameter measurements rather than dynamic tests which would be more suitable for mass production.

5. RECOMMENDATIONS

A program for increasing the frequency coverage of inductor types is in progress under Program Extension II. This program includes the following areas and scope:

Audio frequency (300 to 10,000 cps) -- Designs in Micro-Module shape as entire modules

10 to 200 kc -- adjustable inductors in Micro-Module shape as entire modules

200 to 1500 kc -- inductor microelements

400 to 4500 kc -- adjustable inductor microelements

1.5 to 50 mc inductors -- a second source for microelement design

VHF inductors -- microelement design

Wide-pulse transformers -- designs in Micro-Module shape as entire modules

Pulse transformers -- microelement design

In this program, various types of adjustable constructions will be investigated for adaptation to the Micro-Module Program. In addition, printed wiring in conjunction with magnetic and non-magnetic wafers for vhf designs will be considered. It is recommended that this program, which will cover most Micro-Module needs, be continued.

The availability of a lower permeability, highly stable 50-mc core is being established under Program Extension I. This core will permit improved performance and greater manufacturing yield of higher-frequency cores.

The use of adjustable pot cores in the flatest possible package will be investigated as a part of Program Extension II. This design permits use of bobbin-wound coils and allows inductance adjustment, which is expected to be required in future Micro-Module circuits. This construction also offers a potential cost reduction.

High-frequency choke designs should be investigated for possible use of ferrite micro-element wafers and printed wiring to permit size and cost reduction.

Effort should be directed toward improved and thinner packages. Designs suitable for adaptation to mechanized module assembly techniques are required. Such packages should be integrated with the wafer and be adequately protected to permit storage, and all assembly processes including cleaning, dip soldering, and encapsulation. Improved means of assembly of the coil to a wafer are being considered in Extension II.

Improvements in winding techniques, particularly in the toroidal area, are needed to reduce cost and improve reproducibility. Greater precision in winding should be pursued and semiautomatic machines should be developed to permit multiple machine

operation by one operator. The range of wire capable of being wound by the toroidal machine should be increased to at least AWG 30 from No. 38.

Present test costs for inductors and transformers are excessive and require adaptation of conventional production test techniques. Equipment permitting semiautomatic testing on a dynamic basis should resolve this problem.

Other approaches to the inductor problem should be pursued, including the use of the piezoelectric-filter technique and investigation of semiconductors with inductor-like functions. Distributed R-C filters should be developed to replace coils where practical.

It is also recommended that an investigation be made of the adaptation of the square-loop devices to the Micro-Module form factor for future use. Such devices as magnetic shift registers, transfluxors and memory planes, among others should be considered.

6. LIST OF PERSONNEL

The following personnel participated in the inductor task at the Radio Corporation of America, Semiconductor and Materials Division:

Name	Title	Location
G. Hauser	Engineering Leader	Somerville
J. McKusker	Engineering Leader	Needham
J. Sacco	Engineering Leader	Needham
R. Petrina	Engineer	Somerville
J. Eisenhart	Engineer	Somerville
Z. Stevens	Engineer	Somerville
H. DiLuca	Engineer	Needham
H. Lessoff	Engineer	Needham
R. Costillo	Technician	Somerville
H. Madsen	Technician	Somerville
R. Coons	Technician	Somerville